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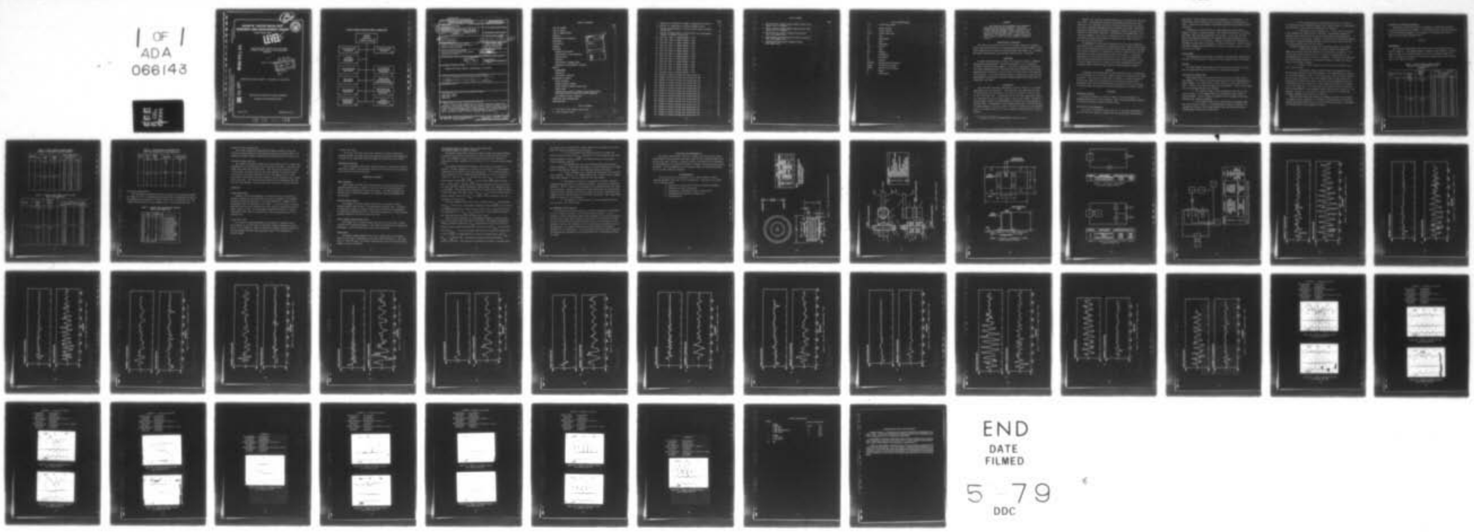

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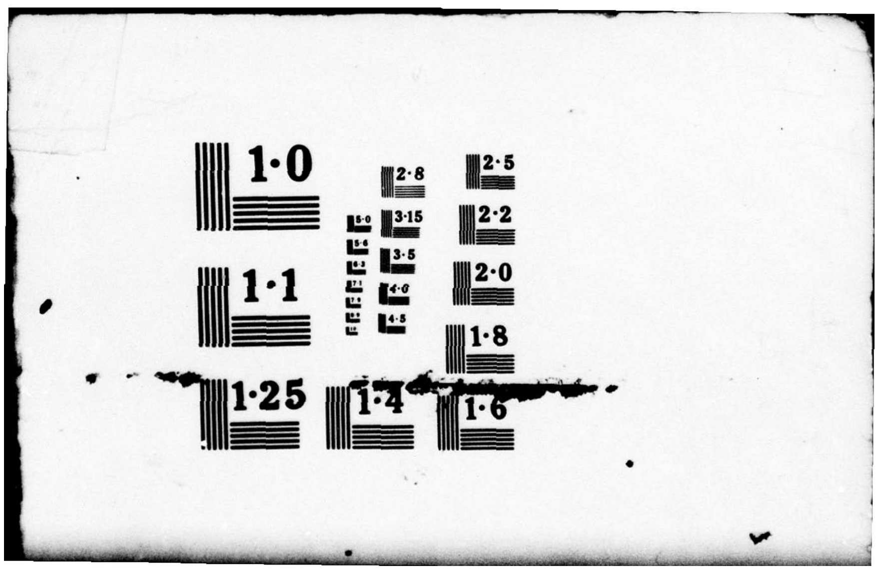
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Bethesda, Maryland 20084

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HIGH IMPACT SHOCK EVALUATION OF THE DIODE ASSEMBLY DESIGN USED IN A 3000-HORSEPOWER GENERATOR

by

Terry S. Ericsen

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RESEARCH AND DEVELOPMENT REPORT

HIGH IMPACT SHOCK EVALUATION OF THE DIODE ASSEMBLY DESIGN USED IN A 3000-HORSEPOWER GENERATOR

March 1979

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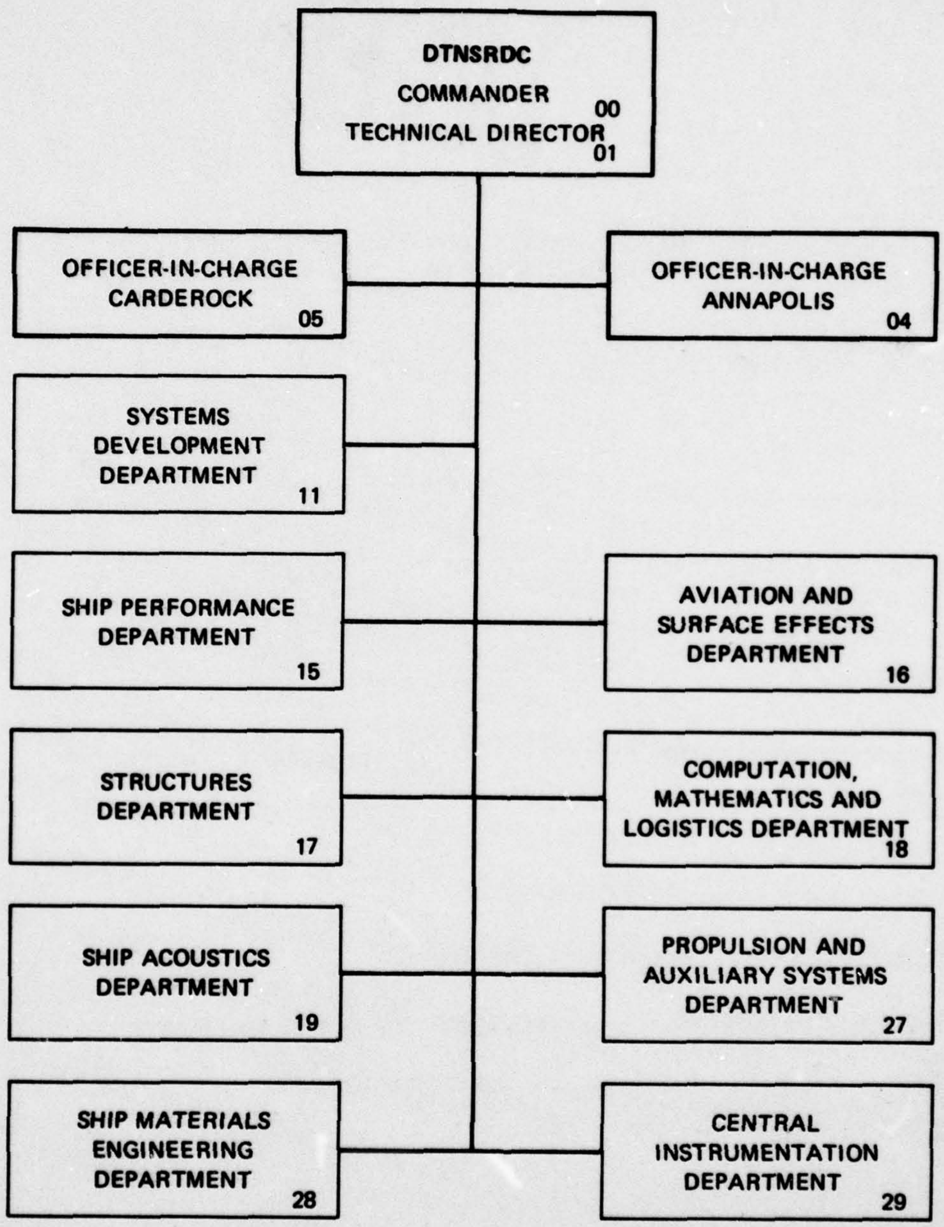

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Two "flat-pak" diode assemblies were evaluated under high impact shock conditions. The results indicate that the assembly design is suitable for use in Navy shipboard equipment, given locking nuts are used for the spring clamp system. It was also recommended that the thickness of the assembly mounting bar be increased in order to improve vibration characteristics.

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LIST OF ABBREVIATIONS

a-c	Alternating current
°C	Degree Celsius
d-c	Direct current
D.U.T.	Device under test
ft	Feet
HI	High impact
Hz	Hertz
hp	Horsepower
i.e.	That is
in.	Inch
max	Maximum
mA	Milliampere
mm	Millimeter
min	Minimum
msec/div	Millisecond per division
mV/amp	Millivolt per ampere
mV/div	Millivolt per division
No.	Number
g	Acceleration

ABSTRACT

Two "flat-pak" diode assemblies were evaluated under high impact shock conditions. The results indicate that the assembly design is suitable for use in Navy shipboard equipment, given locking nuts are used for the spring clamp system. It was also recommended that the thickness of the assembly mounting bar be increased in order to improve vibration characteristics.

ADMINISTRATIVE INFORMATION

This work was performed as part of the in-house supporting technology effort under the Superconductive Propulsion Machinery Projects S0380-SL, Task 16761, sponsored by the Naval Sea Systems Command (SEA 0331H), Mr. A. Chaikin. The effort reported herein was performed under Work Unit 1-2722-100.

BACKGROUND

The work was undertaken as a part of the program to develop a 3000-hp* experimental model generator. The proposed design of the a-c generator included a "flat-pak" diode assembly. A previous investigation conducted by this Center demonstrated that "flat-pak" type power semiconductors and their assemblies were susceptible to failure due to HI shock under certain application conditions. This precipitated the need to determine the nature of those deficiencies in the present "flat-pak" assembly design which would render it vulnerable to HI shock.

INTRODUCTION

The "flat-pak" type power semiconductor, shown in Figure 1, is a design improvement over the "stud-type". The "flat-pak" case construction allows for heat removal from both sides of the device, as opposed to only one side for the "stud-type" case. In addition, the silicon wafer subassembly within the "flat-pak" case is not solder bonded to the case pole faces. Instead of solder bonding, contact to the subassembly is effected by the application of external force, in compression, at the opposite pole faces. This elimination of solder bonding is reported to add to the device reliability, since degradation of the solder bond is one of the predominant long-term causes of device failure.

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*A complete listing of abbreviations is given on page vi.

However, the "flat-pak" presents another set of problems when subjected to HI shock. The mechanical criterion for reliable electrical and thermal operation of the "flat-pak" devices is that the specified level of external force must be applied perpendicularly to the device pole faces. Significant reduction in this force will cause an increase in contact resistance and a decrease in heat removal capability. Additionally, nonperpendicular forces could cause damage to the device by deforming the soft copper pole faces, or by causing excessive shear stress to be applied to the ceramic section of the case or the silicon wafer.

To compensate for the thermal expansion of the "flat-pak" materials, the external force is applied by a spring-clamp system. Under certain conditions, the spring-clamp system can become unstable when subjected to HI shock, thus causing a momentary or intermittent reduction in applied force and the application of large nonperpendicular forces to the device. In addition, discontinuity in electrical operation could result from this instability; this electrical discontinuity could interfer with circuit operation. It is for these reasons that the "flat-pak" type power semiconductors and their assemblies require evaluation when applied in Navy shipboard equipment.

APPROACH

In general, the approach taken in this investigation was to obtain data on the performance of the proposed assembly design in a simulation of HI shock conditions. The results were evaluated to determine if design deficiencies existed which might affect performance in the equipment under HI shock. Measurements were made to determine stability during the shock interval and to ascertain physical damage or electrical degradation as a result of shock.

PROCEDURE

ASSEMBLIES EVALUATED

Two diode assemblies, as shown in Figure 2, were investigated. An assembly contained two "flat-pak" diodes. Each "flat-pak" diode was cooled on one side with a separate liquid cooled heat sink.

MODIFICATION TO THE ASSEMBLIES

As a result of earlier HI shock work done on "flat-pak" assemblies, it was found that the clamp nuts, which retain the spring force, would loosen

under shock. This loosening caused severe porblems in the assemblies. The problem was solved by using a back up nut which locked the retaining nut in place. Locking nuts were added to the 3000-hp generator diode assembly before evaluation.

In addition, it was found that the spring gages were susceptible to damage as a result of normal handling. This caused uncertainty as to whether the proper force was being maintained on the clamp. It was felt that the gages could adequately determine the clamping force during mounting if the indicator was set at zero initially. However, the gages were inadequate to determine if clamp force was reduced as a result of HI shock. A set of calipers was used to measure spring deflection, and thus the relative change in spring force due to HI shock.

SHOCK MACHINE

The lightweight shock machine as specified in MIL-STD-202C, Method 207A, was used for the evaluation. Fixture 207-6 was selected as the test fixture.

MOUNTING

The diode assembly was mounted to the 207-6 fixture as shown in Figure 3. The G-10 epoxy-glass board was required for electrical isolation.

APPLICATION OF HAMMER DROPS

Three hammer blows were applied along each of the three major axes of the assembly. The sequence of blows along each axis was in ascending order of hammer heights, i.e., first blow at 1-foot, second at 3 feet, and third at 5 feet. A total of nine blows was applied to each assembly. Prior to each hammer drop the following procedure was followed:

1. The reverse leakage current was measured using the circuit shown in Figure 4. The leakage current was recorded for three values of applied voltage. The d-c voltage was applied, and the leakage current was measured with a digital multimeter.

2. The forward voltage drop of each device was measured using the circuit shown in Figure 5. The measurement was made by applying a d-c through both devices in the forward biased state, and then measuring the corresponding voltage drop of each device.

3. The spring deflection was measured using a set of calipers. The measurement was an indirect measure of the relative change in spring deflection caused by HI shock, and not considered to be absolute.

4. The position of the retaining nuts on the studs of the spring clamp assemblies was marked prior to each blow. The marking consisted of drawing a line on the hex face of the nut and extending it perpendicularly on the top face of the spring. Rotation of the nut would be observed by noting the angle of separation between the line on the nut and the line on the top of the spring after each blow of HI shock.

During the hammer drop interval, the following procedure was followed:

1. Instantaneous changes in forward voltage drop during the hammer drop interval were measured with the circuit shown in Figure 6. The voltage drops across points a-c and b-c of Figure 6 were monitored by an oscilloscope with its inputs set for a-c coupling. In addition, the accelerometer output being monitored by a Visicorder was used to trigger the oscilloscope at the instant of impact.

2. Direct current during the shock interval was measured with a strip chart recorder.

3. Acceleration during the shock interval was measured at the 207-6 fixture, and also at the diode assembly. The accelerometer was attached to the diode assembly by means of a G-10 epoxy-glass block as shown in Figure 2. The G-10 block was affixed to the fuse mounting bolts by holes drilled and tapped into the heads of the bolts. The G-10 block was designed so that the accelerometer could be mounted in the three major axes parallel to the direction of the hammer drop. The G-10 block also provided electrical isolation for the accelerometer. The measurement system used is shown in Figure 6. The frequency response of the system had a cutoff at 500 Hz to eliminate high-frequency components which were not of interest.

After the nine blows were applied, the assembly components were checked for damage by visual inspection. In addition, the hermeticity of the diode package was checked using the Fine and Gross Leak Tests described in MIL-HDBK-750B, Method 1071.1 (Test Conditions D and H).

PROCEDURE FOR EXPLORATORY VIBRATION

In addition to the shock procedures outlined, an exploratory vibration procedure was performed on Assembly 2. The objective was to obtain an estimate of the low-frequency response of the assembly. The response was visually observed and resonance phenomena noted.

RESULTS

MEASUREMENTS

The results of measurements made before and after each hammer blow are given in Table 1-4. The maximum change in leakage current measured is approximately 0.5 mA; in d-c forward voltage, 0.07 volt; in caliper reading, 1/64 inch. In addition, the results of retaining nut marking observation indicate that no nut rotation occurred.

TABLE 1 - DEVICE REVERSE LEAKAGE CURRENT MEASURED AFTER EACH HAMMER BLOW FOR ASSEMBLY 1

Assembly No.	Device	Previous Blow Axis	Previous Hammer Height, ft.	Reverse Current in mA at 25° C, V_{rrm} = Volts: 100	300	600
1	1	Initial	Initial	0.70	2.09	4.18
		x	1	0.71	2.12	4.24
		x	3	0.71	2.12	4.25
		x	5	0.71	2.13	4.27
		y	1	0.71	2.13	4.27
		y	3	0.72	2.14	4.29
		y	5	0.72	2.14	4.29
		z	1	0.72	2.17	4.35
		z	3	0.73	2.17	4.35
		z	5	0.74	2.17	4.36
	2	Initial	Initial	0.61	1.90	4.19
		x	1	0.70	2.11	4.24
		x	3	0.70	2.11	4.25
		x	5	0.70	2.12	4.26
		y	1	0.70	2.12	4.27
		y	3	0.71	2.13	4.29
		z	5	0.72	2.14	4.29
		z	1	0.71	2.16	4.34
		z	3	0.72	2.17	4.35
		z	5	0.72	2.17	4.35

TABLE 2 - DEVICE REVERSE LEAKAGE CURRENT MEASURED AFTER HAMMER BLOW FOR ASSEMBLY 2

Assembly No.	Device	Previous Blow Axis	Previous Hammer Height, ft	Reverse Leakage Current in mA at 25° C, V_{rrm} = Volts		
				100	300	600
2	1	Initial	Initial	0.70	2.08	4.17
		z	1	0.71	2.13	2.28
		z	3	0.75	2.25	4.51
		z	5	0.77	2.31	4.62
		y	1	0.70	2.08	4.17
		y	3	0.70	2.08	4.17
		y	5	0.70	2.08	4.16
		x	1	0.70	2.09	4.17
		x	3	0.70	2.09	4.16
		x	5	0.70	2.09	4.17
	2	Initial	Initial	0.69	2.08	4.17
		z	1	0.71	2.14	4.33
		z	3	0.75	2.23	4.50
		z	5	0.76	2.31	4.62
		y	1	0.69	2.08	4.16
		y	3	0.69	2.08	4.16
		y	5	0.69	2.07	4.16
		x	1	0.69	2.08	4.16
		x	3	0.69	2.08	4.16
		x	5	0.69	2.08	4.17

TABLE 3 - DIRECT-CURRENT FORWARD VOLTAGE DROPS AFTER EACH HAMMER BLOW

Assembly	Previous Blow Axis	Previous Hammer Height ft	Forward Voltage Drops (Volts) I = 30 Ampere Direct Current	
			Device 1	Device 2
1	Initial	Initial	0.758	0.924
	x	1	0.748	0.943
	x	3	0.740	0.958
	x	5	0.759	0.931
	y	1	0.759	0.916
	y	3	0.760	0.913
	y	5	0.762	0.910
	z	1	0.770	0.950
	z	3	0.780	0.890
	z	5	0.762	0.920
2	Initial	Initial	0.772	0.930
	z	1	0.764	0.930
	z	3	0.747	0.924
	z	5	0.750	0.918
	y	1	0.770	0.936
	y	3	0.769	0.946
	y	5	0.736	0.935
	x	1	0.760	0.931
	x	3	0.768	0.953
	x	5	0.770	0.926

TABLE 4 - GAGE READINGS AND RETAINING NUT POSITIONS OBSERVED AFTER EACH HAMMER BLOW

Assembly No.	Previous Blow Axis	Previous Hammer Height ft	Independent Gage Reading in.	Observed Rotation of Spring Clamps Nuts
	Initial	Initial	3/64	None
	x	1	3/64	
	x	3	4/64	
1	x	5		
	y	1		
	y	3		
	y	5		
	z	1		
	z	3		
	z	5	4/64	None
	Initial	Initial	5/64	None
	z	1		
	z	3		
	z	5		
2	y	1		
	y	3		
	y	5		
	x	1		
	x	3		
	x	5	5/64	None

Acceleration Measurements

The acceleration measurements during the hammer drop intervals are given in Figures 7A to 7N. The maximum peak accelerations are summarized in Table 5. The maximum peak acceleration at Fixture 207-6 is 214 g during Blow 224. The maximum peak acceleration at the assembly fuse is 171 g during Blow 215.

TABLE 5 - MAXIMUM PEAK ACCELERATION MEASURED DURING EACH HAMMER BLOW

Blow No.	Table Maximum Acceleration g	At Devices in Assembly Maximum g	Blow Axis	Blow Description
207	86	79	x	1 ft Back Assembly 1
208	193	107	x	3 ft Back Assembly 1
209	193	129	x	5 ft Back Assembly 1
210	*	*	y	1 ft Vertical Assembly 1
211	36	54	y	3 ft Vertical Assembly 1
212	29	64	y	5 ft Vertical Assembly 1
213	43	93	z	1 ft Side Assembly 1
214	75	161	z	3 ft Side Assembly 1
215	171	171	z	5 ft Side Assembly 1
216	32	48	z	1 ft Side Assembly 2
217	*	*	z	3 ft Side Assembly 2
218	*	*	z	5 ft Side Assembly 2
219	*	*	x	1 ft Vertical Assembly 2
220	37	68	y	3 ft Vertical Assembly 2
221	86	86	y	5 ft Vertical Assembly 2
222	80	80	x	1 ft Back Assembly 2
223	165	118	x	3 ft Back Assembly 2
224	214	129	x	5 ft Back Assembly 2

*No blow record obtained.

Change in Forward Voltage Drop

The results showing the instantaneous change in forward voltage drop across the diodes during the shock interval are given in Figures 8A-8P. The maximum instanteous change in forward voltage drop measured is 34 millivolts.

Helium and Bubble Leak Test

The results of helium and bubble leak tests indicated that no significant degradation of case hermeticity had occurred due to HI shock. The helium and bubble leak tests were performed twice. Both tests were performed on a pass or fail basis. The first time the test was performed, the devices failed. It was then found during dissection of one of the diodes that the copper pole faces of this device type were removable, and not designed to be a bonded part of the case. The leak tests were repeated on the remaining diodes with the pole faces removed. The second leak test resulted in no device failures.

INSPECTION

Visual Before Shock

Assembly 1 was not disassembled for inspection before application of HI shock. However, it was noted that the spring of Assembly 1 was slightly twisted along the axis parallel to its longest dimension. Assembly 2 was disassembled prior to application of HI shock. It was noted that the spring-gage was bent and did not indicate zero force when the retaining nuts had no torque applied to them. The spring gage was bent badly enough to indicate approximately 500 pounds of negative force with zero applied torque on the retaining nuts.

Visual After Shock

As a result of visual inspection of the assembly's components after shock testing, it was found that no observable physical damage had occurred to any of the components. That is, there was no damage with the exception of the spring gages which have been previously shown to be susceptible to physical damage.

Internal After Shock

One of the "flat-pak" devices was selected for internal inspection. Internal inspection of diode case inner surfaces and silicon wafer subassembly revealed that no significant physical damage had occurred due to HI shock.

EXPLORATORY VIBRATION

Two low reasonance points were observed during the exploratory vibration. Referring to Figure 2, low resonance was found at 30.5 Hz in the A-A direction and at 48.5 Hz in the B-B direction.

DISCUSSION OF RESULTS

SHOCK CRITERION

The HI shock criterion used was more severe than that specified in the equipment specification. However, it was felt that this criterion was of greater value in determining design deficiencies. Past NRL experience with various types of shipboard equipment and components provided confidence in this decision.

REVERSE LEAKAGE CURRENT

The changes in reverse leakage current were on the order of those changes normally expected due to the measurement techniques used. Therefore, no significant changes in leakage current could be found in the measurement. The measurement demonstrated that no significant degradation in reverse voltage blocking capability had occurred due to HI shock.

DIRECT CURRENT FORWARD VOLTAGE DROP

The changes in d-c forward voltage drop are also on the order of those expected due to measuring technique. The results indicated that no significant degradation of this characteristic occurred due to HI shock.

SPRING FORCE

The maximum change measured by the set of calipers was due to twisted nature of the spring. Measurement on one side indicated 3/64 inch. The other side indicated 4/64 inch. The results indicated that there was no reduction of spring force due to HI shock.

INSTANTANEOUS CHANGE OF FORWARD VOLTAGE DROP DURING SHOCK AND POSSIBLE EFFECTS ON CIRCUIT OPERATION

The maximum instantaneous change in forward voltage drop observed during HI shock is not expected to significantly affect circuit operation in this case. This judgment is based on the equipment manufacturer's analysis of steady-state current imbalance and the inclusion of the observed effects during shock.

The equipment manufacturer intends to use 28 diodes electrically in parallel. Current imbalance is a function of the variation in diode forward voltage-drop as provided by the device manufacturer. The equipment manufacturer calculates that the maximum allowed deviation in forward voltage drop is 0.238 volt. That is, $V_{F_{max}} - V_{F_{min}} \leq 0.238$ volt, where $V_{F_{max}}$ is the maximum diode forward voltage drop, and $V_{F_{min}}$ is the minimum diode forward voltage drop. In this case, 0.238 volt is the maximum permissible deviation that will not cause the 90^{o} C junction temperature design margin to be exceeded by any of the diodes. This calculation assumes that 27 diodes have a nominal forward voltage drop (V_{FN}, where $V_{FN} = V_{Fmin} + (V_{F_{max}} - V_{F_{min}})/2$) and one diode has the minimum forward voltage drop ($V_{F_{min}}$). Because of this assumption, this calculation is not worst case.

The worst condition would occur if the 27 diodes had $V_{F_{max}}$ and one diode had $V_{F_{min}}$. In this case, the maximum permissible deviation would be 0.119 volt. The equipment manufacturer states that the devices will be supplied such that, "at approximately 1 kA, $V_{F_{max}} - V_{F_{min}} \leq 0.020$ volt." Under normal conditions, this variation would be within the permissible limits.

Under HI shock conditions, the instantaneous change in forward voltage drop, due to shock, should be taken into account. The maximum instantaneous change in forward voltage drop ($V_{F_{max}}$) observed due to shock is 0.034 volt. Using the worst condition assumption, 27 diodes will have $V_{F_{max}}$ and one diode will have $V_{F_{min}}$. If it can be assumed that shock will cause the voltage drop of the 27 diodes to change and will not affect the single diode, then $V_{F_{max}} + \Delta V_{F_{max}} - V_{F_{min}} \leq 0.054$ volt. The deviation would be within the maximum limit of 0.119 volt. This analysis is considered sufficient to conclude that

the circuit will be unaffected by forward voltage drop variation due to shock under the following assumptions and conditions:

1. It is very unlikely that shock will affect 27 diodes and leave the specific diode with $V_{F_{min}}$ unaffected. In all likelihood, each diode will be affected to various degrees. The results would be a less severe current imbalance condition.

2. The analysis does not include simultaneous shock and short-circuit conditions. Under these conditions, the current imbalance due to shock would be insignificant compared to the imbalance caused by the short.

3. Current imbalance due to distributed impedances is not included in the analysis. Moreover, the changes observed due to shock would be insignificant when compared to start-up, shut-down, and load changes.

4. The analysis is based on a comparison to the 40^{o} C junction temperature margin which is an average calculation. The HI shock condition is transient. The 40^{o} C margin is not expected to be maintained under such transient conditions. Moreover, taking into account thermal lag, the instantaneous change in forward voltage would cause less change in junction temperature than suggested by the comparison made to the average calculation. Thus, significant margin is inherent in the calculation.

5. The analysis is based primarily on the assumption that lock nuts are used in the diode clamps.

LOW RESONANCE DURING VIBRATION

The exploratory vibration applied to the diode assembly was not intended to be an in-depth evaluation of its vibration characteristics. It was designed to provide information which would supplement the HI shock evaluation. The two low resonance points observed (30.5 Hz in the A-A direction and 48.50 Hz in the B-B direction) supported the good HI shock characteristics of the assembly. However, the resonance in the A-A direction was considered too low. The amplitude of the motion observed could cause problems with adjacent assemblies in its application. It was determined that this could be corrected by increasing the thickness of the supporting bus bar to approximately equal its width.

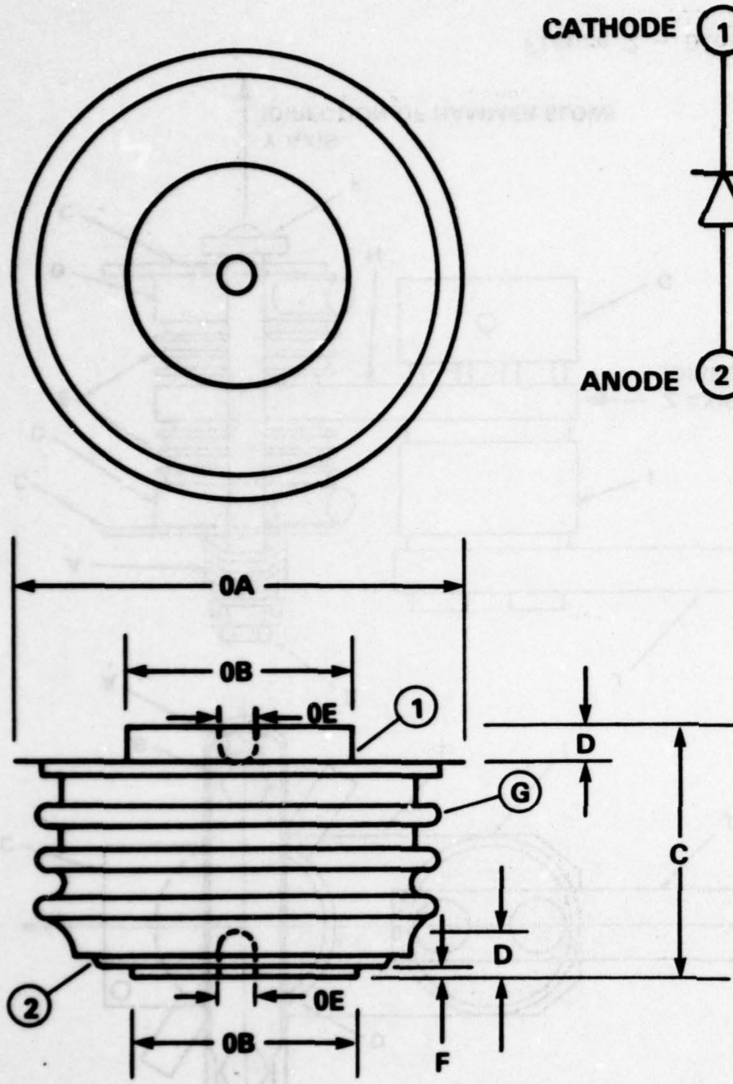
CONCLUSION AND RECOMMENDATION

The results indicate that there are no design deficiencies which would hinder diode or diode assembly performance under HI shock conditions when locking nuts are used. Results of vibration analysis indicated that the thickness of the mounting bus bar should be increased to prevent unnecessary motion during vibration. It is recommended that the assembly design be considered suitable for use in Navy shipboard equipment.

ACKNOWLEDGMENTS

The shock facilities and expertise of Mr. Harold Forkois of Naval Research Laboratory were used in the investigation. Assistance was provided in the following areas:

1. Selection of shock machine fixture and mounting hardware.
2. Procedure for shock application.
3. Measurement of mechanical response during shock.
4. Determination of mechanical deficiencies.
5. Recommendations.

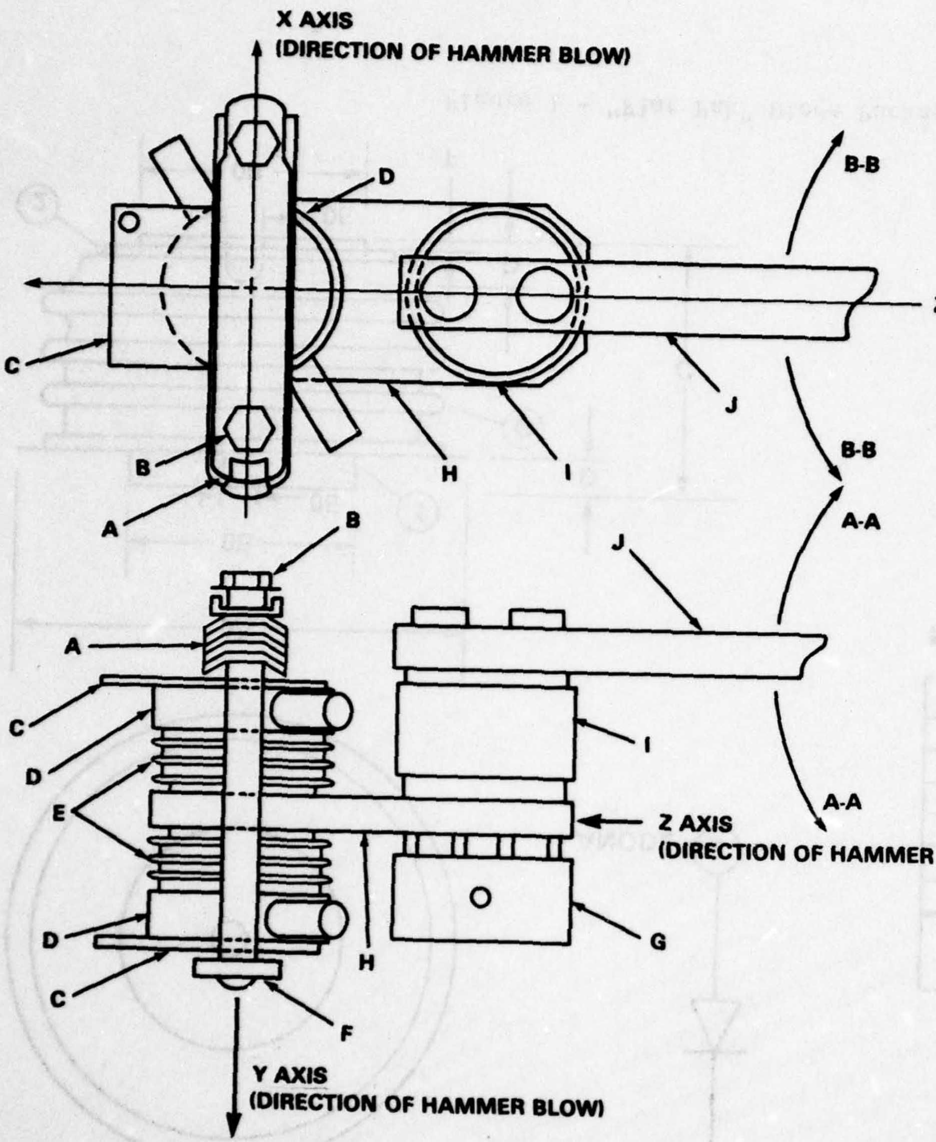


SYMBOL	INCH MIN	INCH MAX	MM MIN	MM MAX	NOTE
0A		2.000		50.80	
0B	1.240	1.260	31.50	32.00	
C	1.000	1.060	25.40	26.92	
D	0.80		2.03		
0E	0.136	0.146	3.45	3.71	
F	.034		0.86		
G					1

NOTE:

1. GLAZED CERAMIC INSULATOR WITH 1.00 MIN. SURFACE CREEPAGE (25.40mm)

Figure 1 - "Flat Pak" Diode Package Construction



SYMBOL	COMPONENT
A	SPRING
B	RETAINING NUT
C	ELECTRICAL CONNECTION
D	WATER-COOLED HEAT EXCHANGER
E	DIODE (SEE FIGURE 1)
F	CLAMP
G	G-10 ACCELEROMETER MOUNT
H	COPPER BUS
I	1200 AMPERE FUSE
J	COPPER MOUNTING BUS
A-A	MOTION DURING VIBRATION
B-B	MOTION DURING VIBRATION

Figure 2 - Diode Assembly Tested

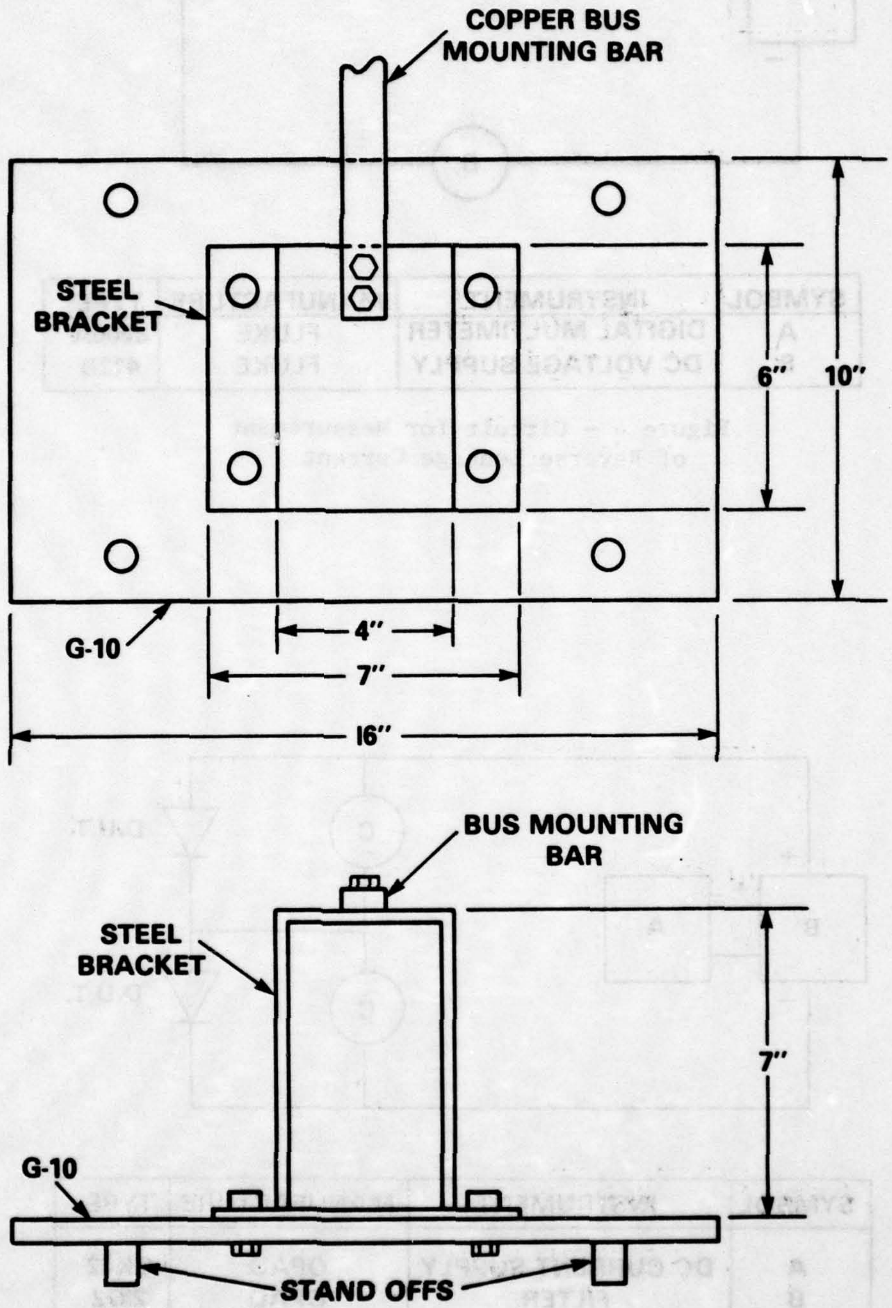
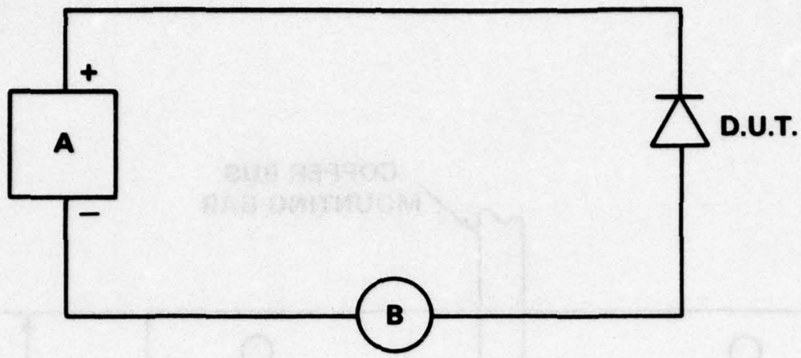
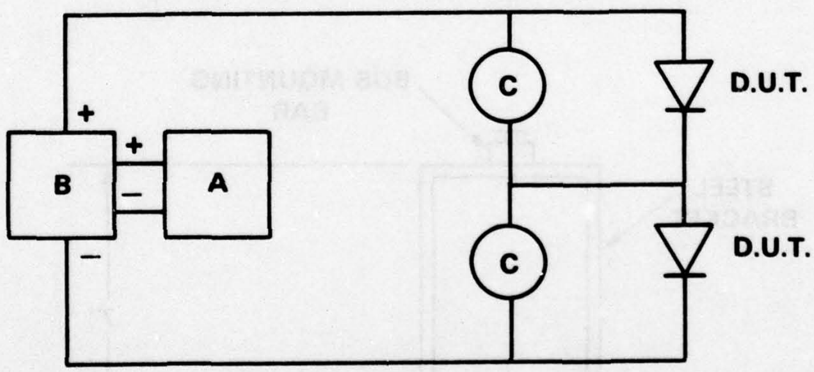


Figure 3 - Mounting for Assemblies to Adapt to Shock Machine Fixture



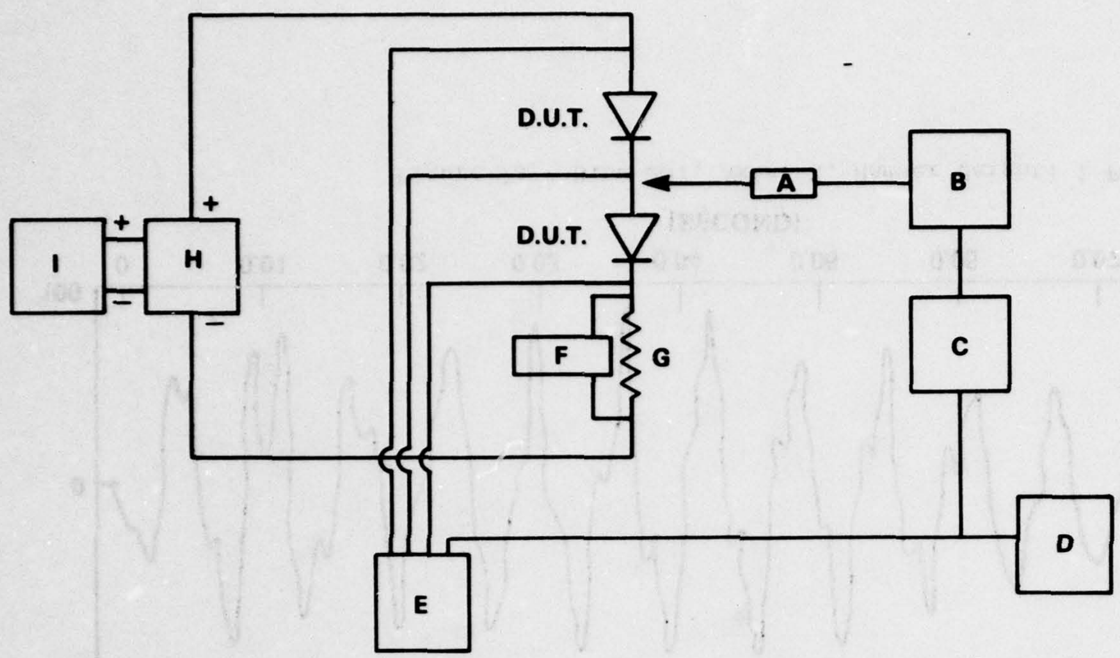
SYMBOL	INSTRUMENT	MANUFACTURE	TYPE
A	DIGITAL MULTIMETER	FLUKE	8000A
B	DC VOLTAGE SUPPLY	FLUKE	412B

Figure 4 - Circuit for Measurement of Reverse Leakage Current



SYMBOL	INSTRUMENT	MANUFACTURE	TYPE
A	DC CURRENT SUPPLY	OPAD	GK42
B	FILTER	OPAD	2372
C	DIGITAL MULTIMETER	FLUKE	8000A

Figure 5 - Circuit for Measurement of Direct Current Forward Voltage Drop



SYMBOL	INSTRUMENT	MANUFACTURE	TYPE
A	ACCELEROMETER	RNDRVC	2221 MIA
B	CHARGE AMPLIFIER	RNDRVCO	2713
C	CURRENT AMPLIFIER	HONEYWELL	T6GA-500
D	VISICORDER	HONEYWELL	1508
E	OSSICLOSCOPE	TEKTRONIX	7633, PLUG-INS 7A18, 7A22, 7B50
F	STRIP CHART RECORDER	HEWLET PACKARD	MOSELEY 680
G	SHUNT	WESTON	50mV/100Amps
H	FILTER	OPAD	2372
I	DC CURRENT SUPPLY	OPAD	GK42

Figure 6 - Circuit for Measurement of Acceleration and Instantaneous Changes in Forward Voltage Drop

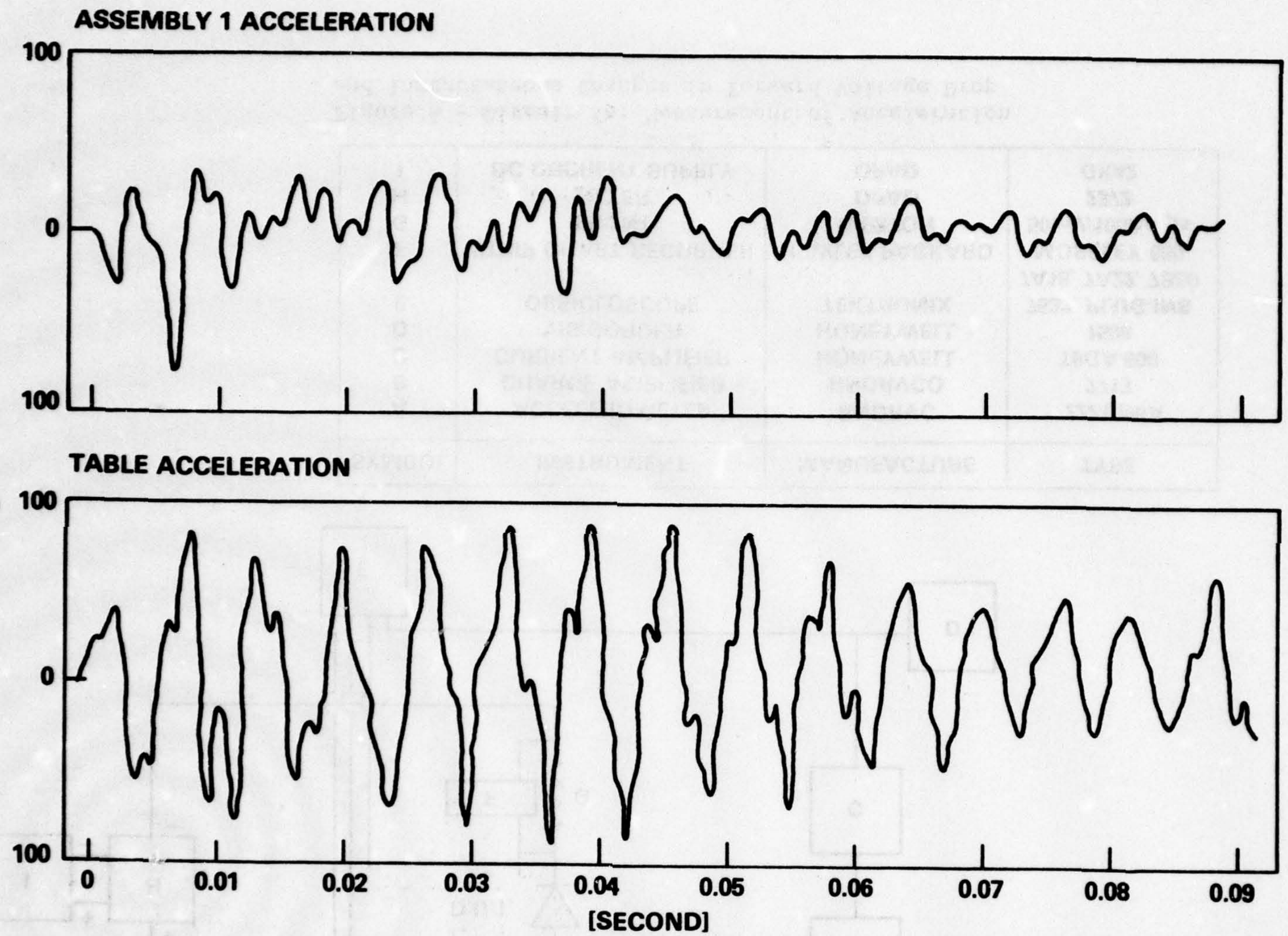


Figure 7a - Blow 207, Axis: X, Hammer Height: 1 Foot

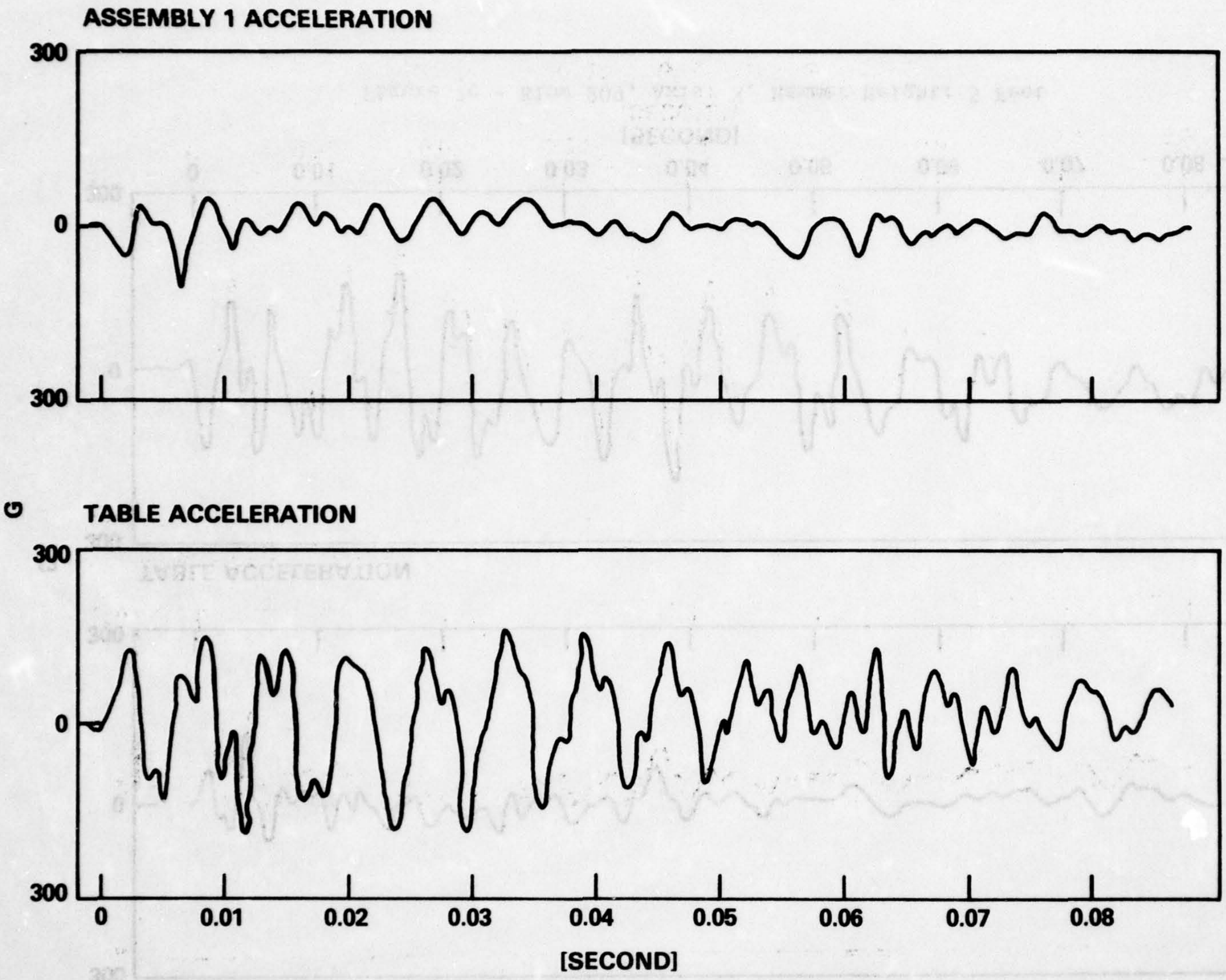


Figure 7b - Blow 208, Axis: X, Hammer Height: 3 Feet

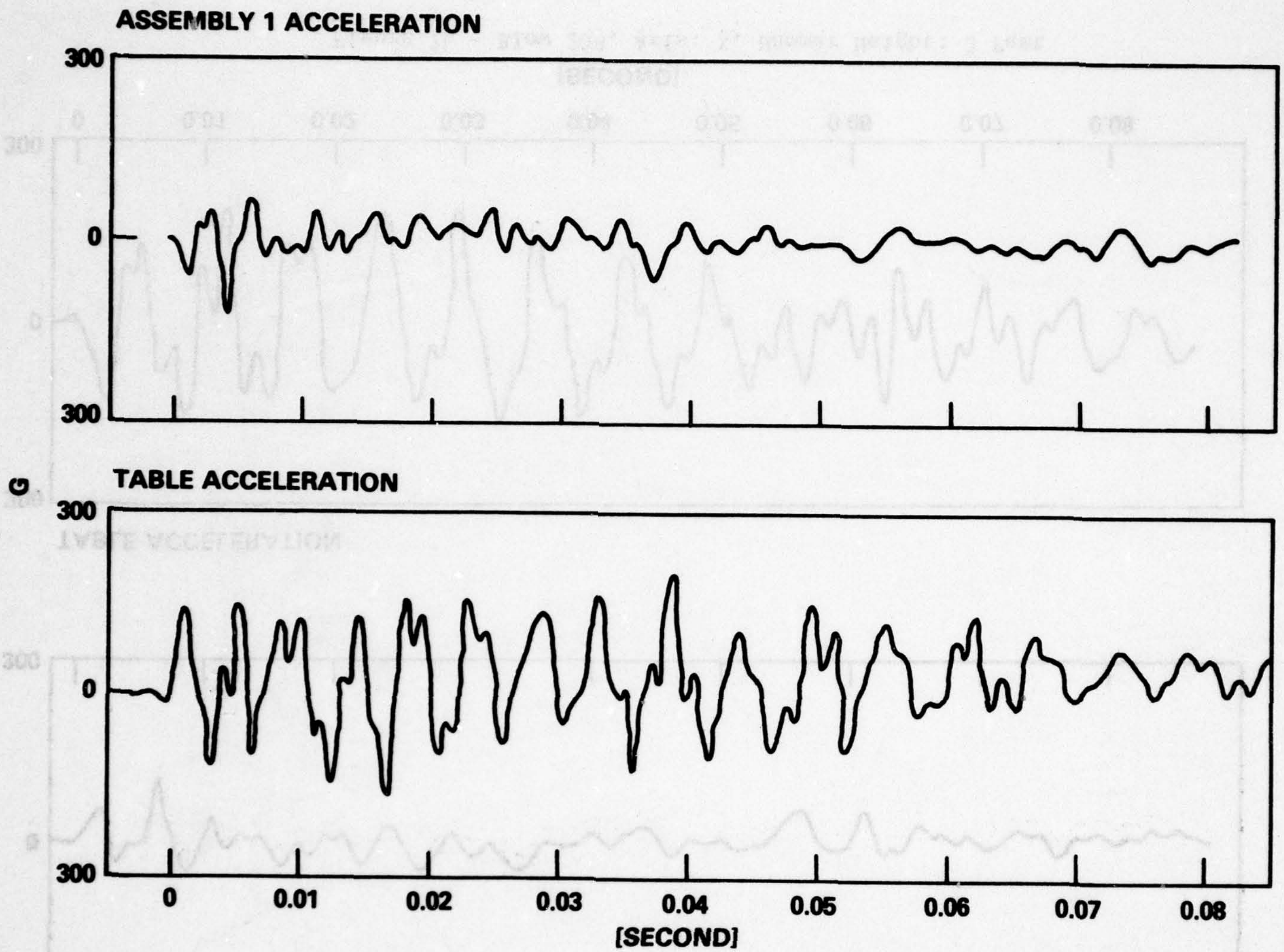


Figure 7c - Blow 209, Axis: X, Hammer Height: 5 Feet

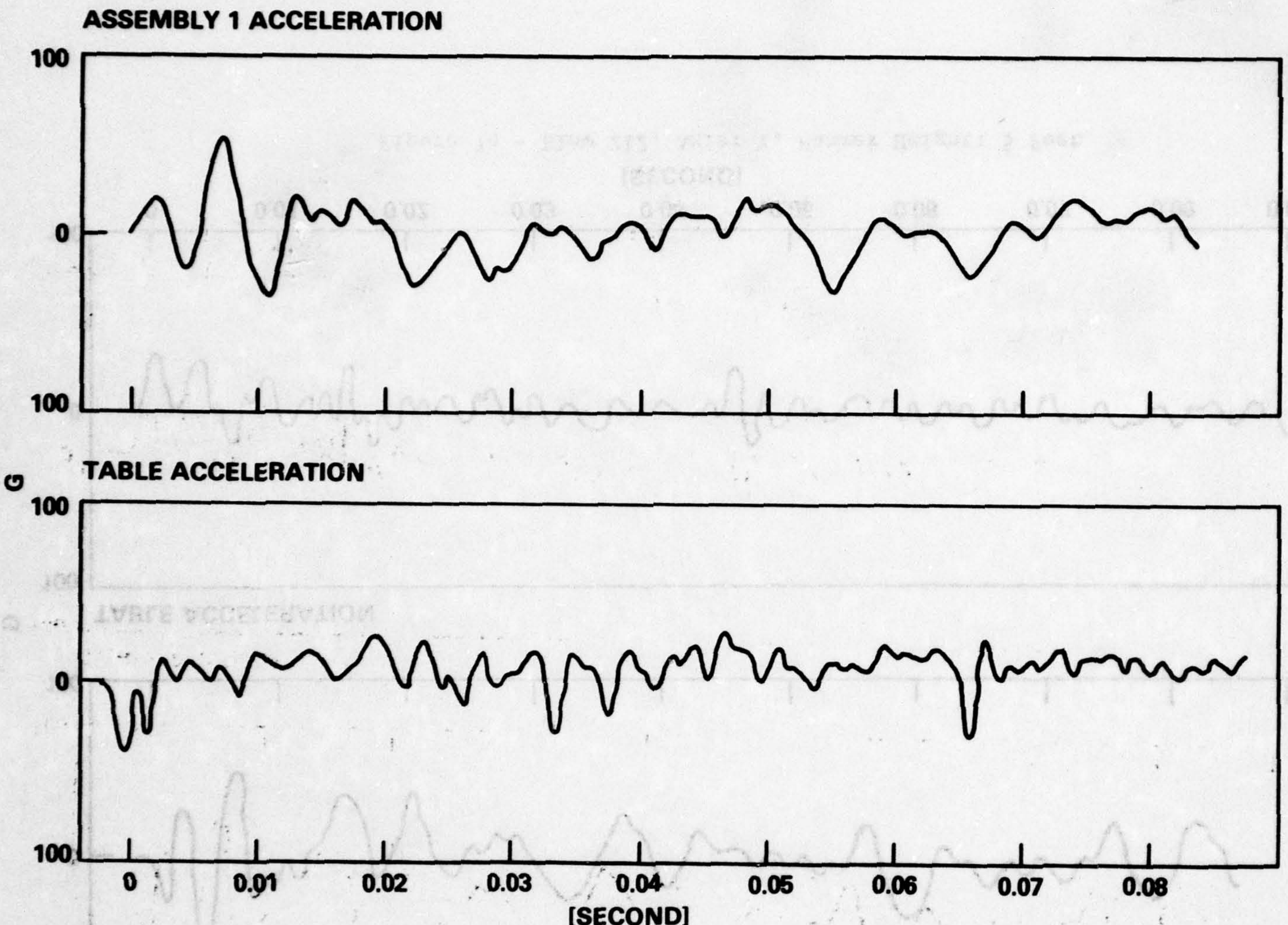


Figure 7d - Blow 211, Axis: Y, Hammer Height: 3 Feet

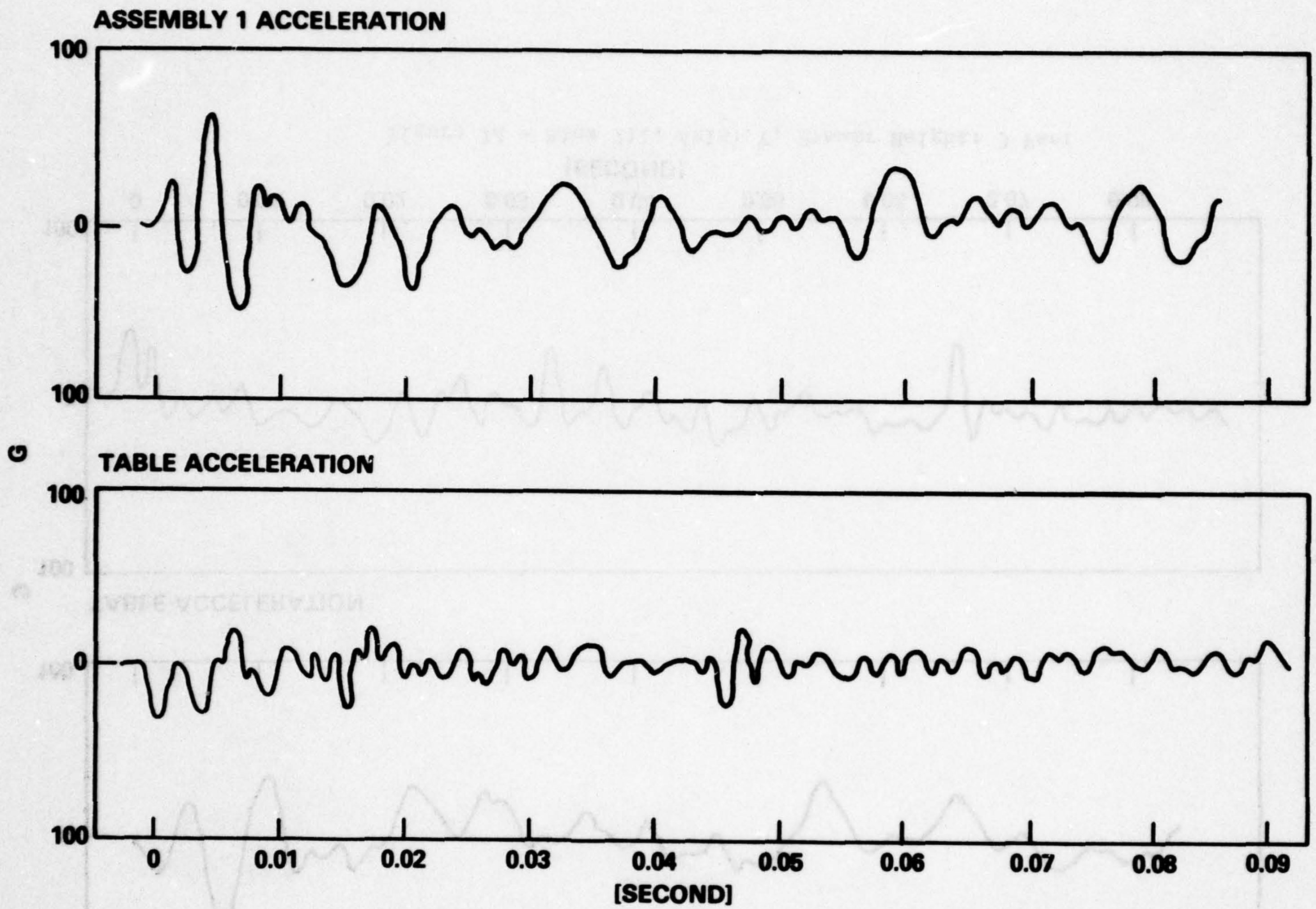


Figure 7e - Blow 212, Axis: Y, Hammer Height: 5 Feet

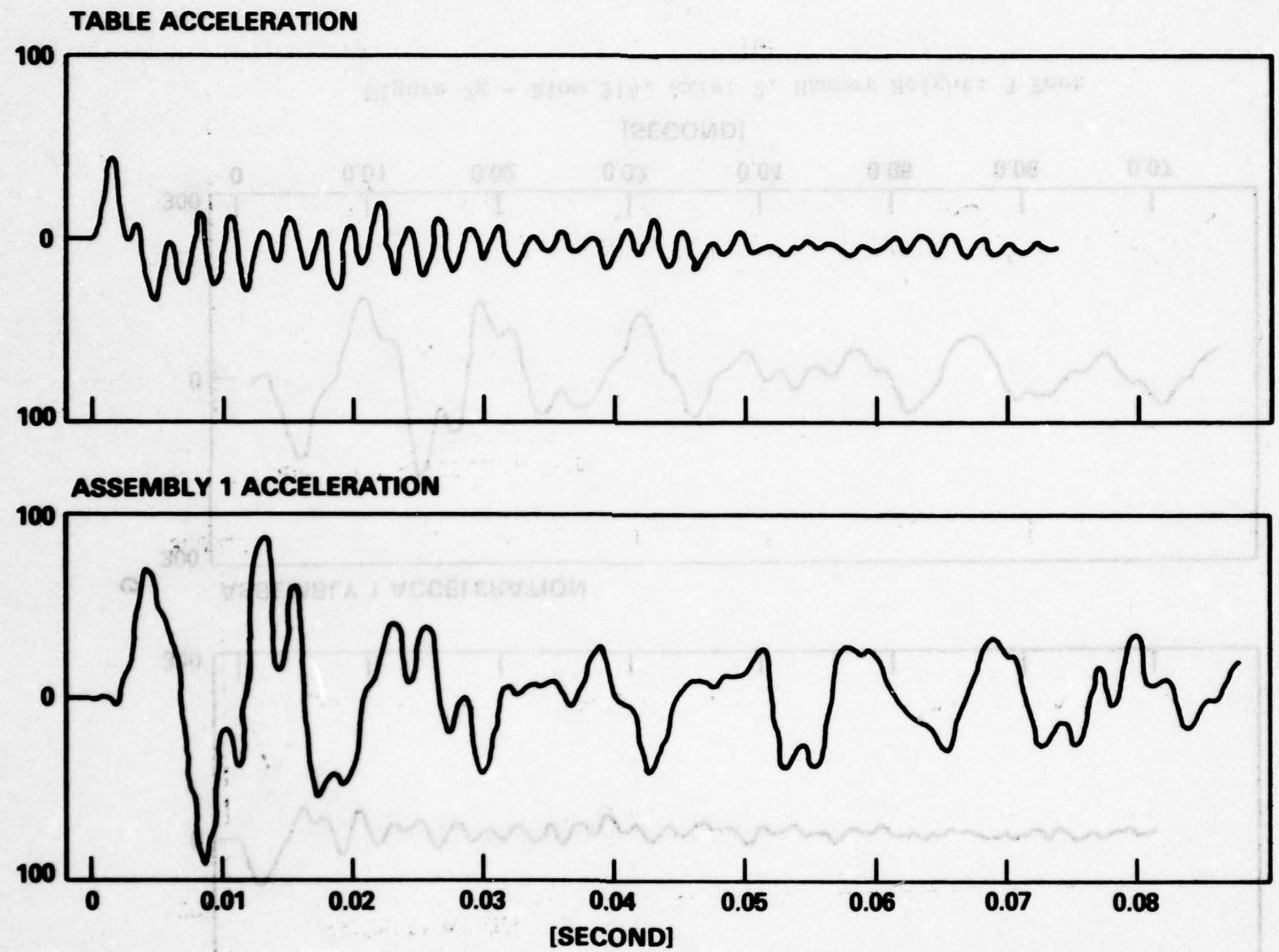


Figure 7f - Blow 213, Axis: Z, Hammer Height: 1 Foot

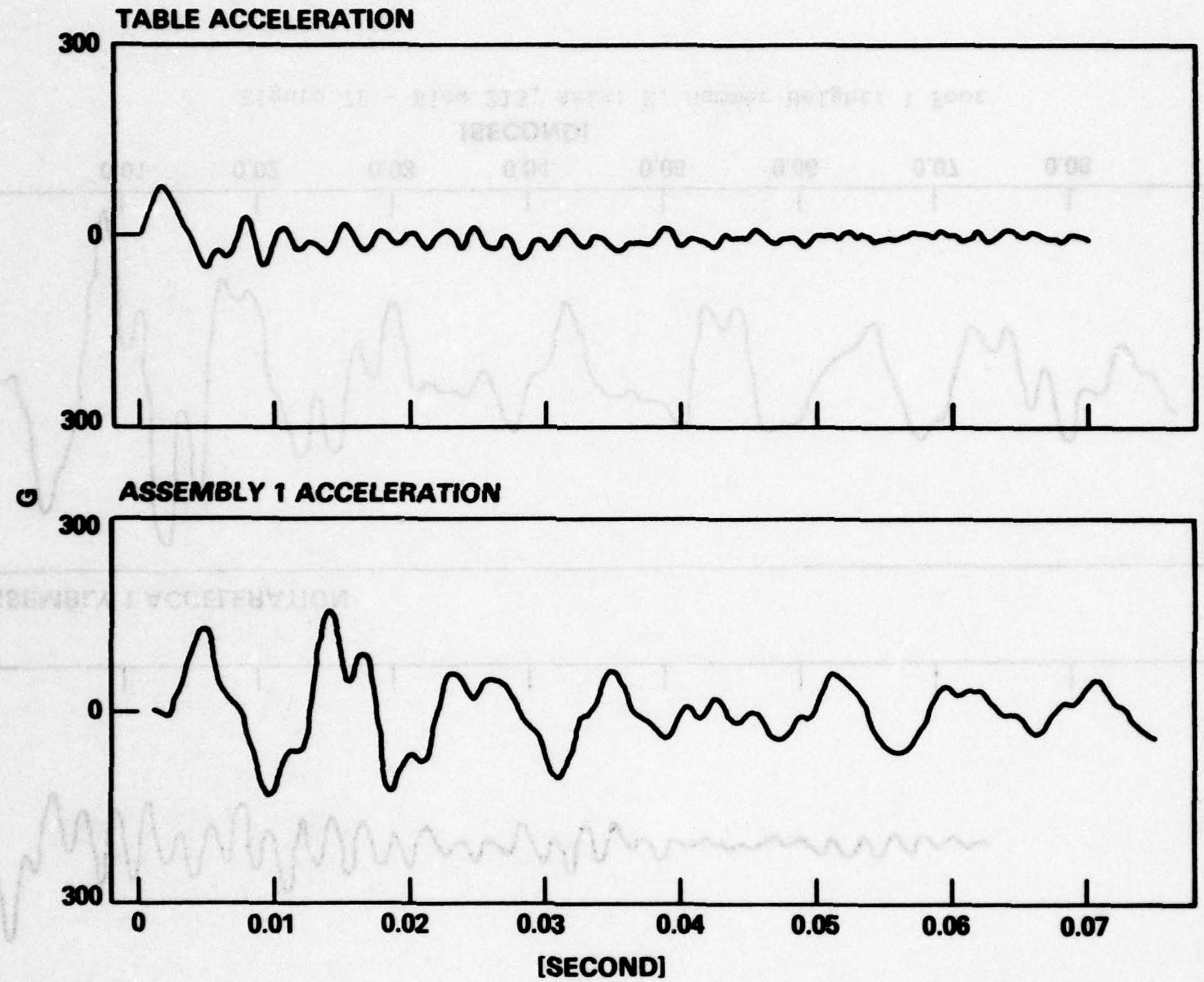


Figure 7g - Blow 214, Axis: Z, Hammer Height: 3 Feet

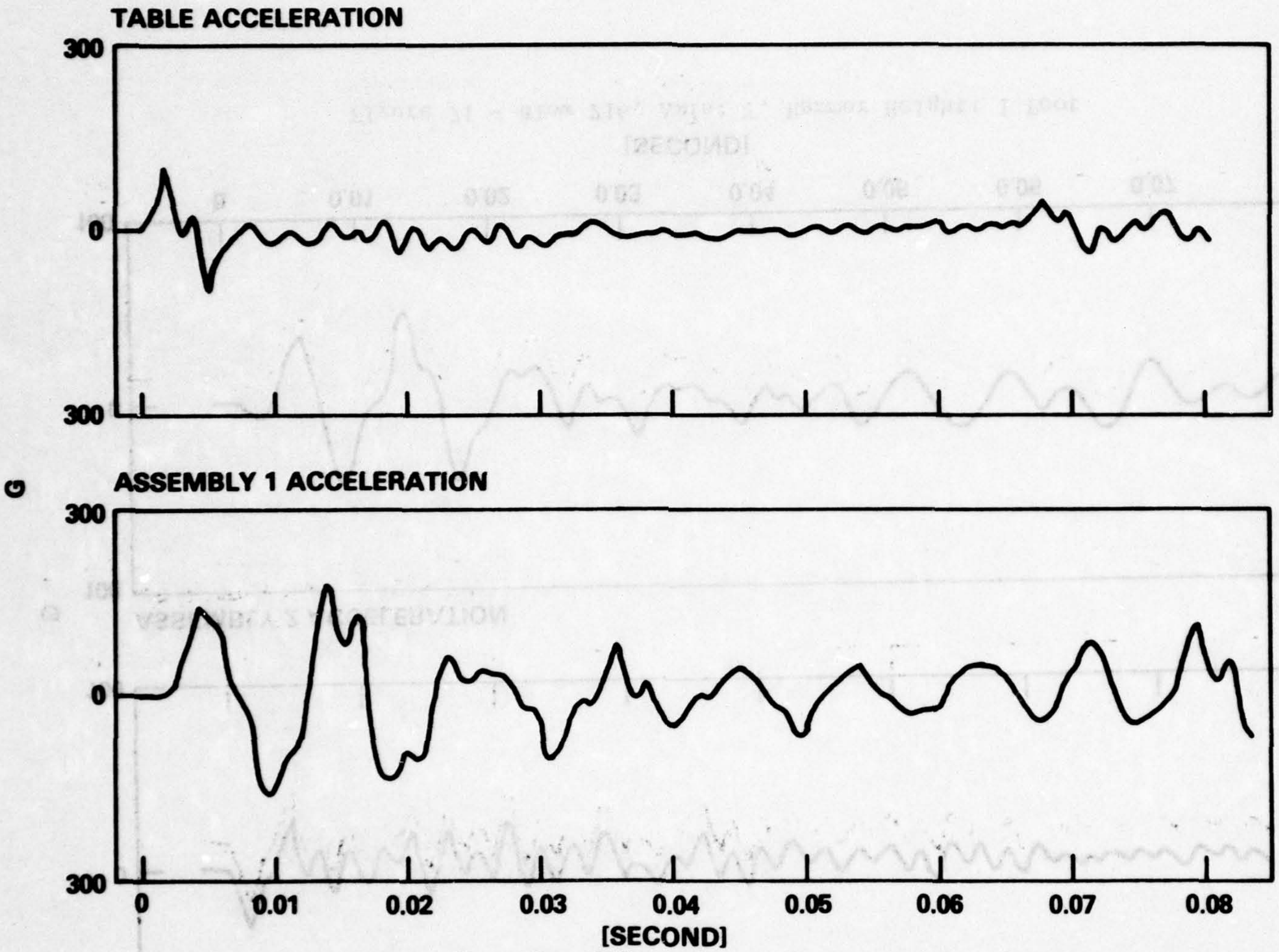


Figure 7h - Blow 215, Axis: Z, Hammer Height: 5 Feet

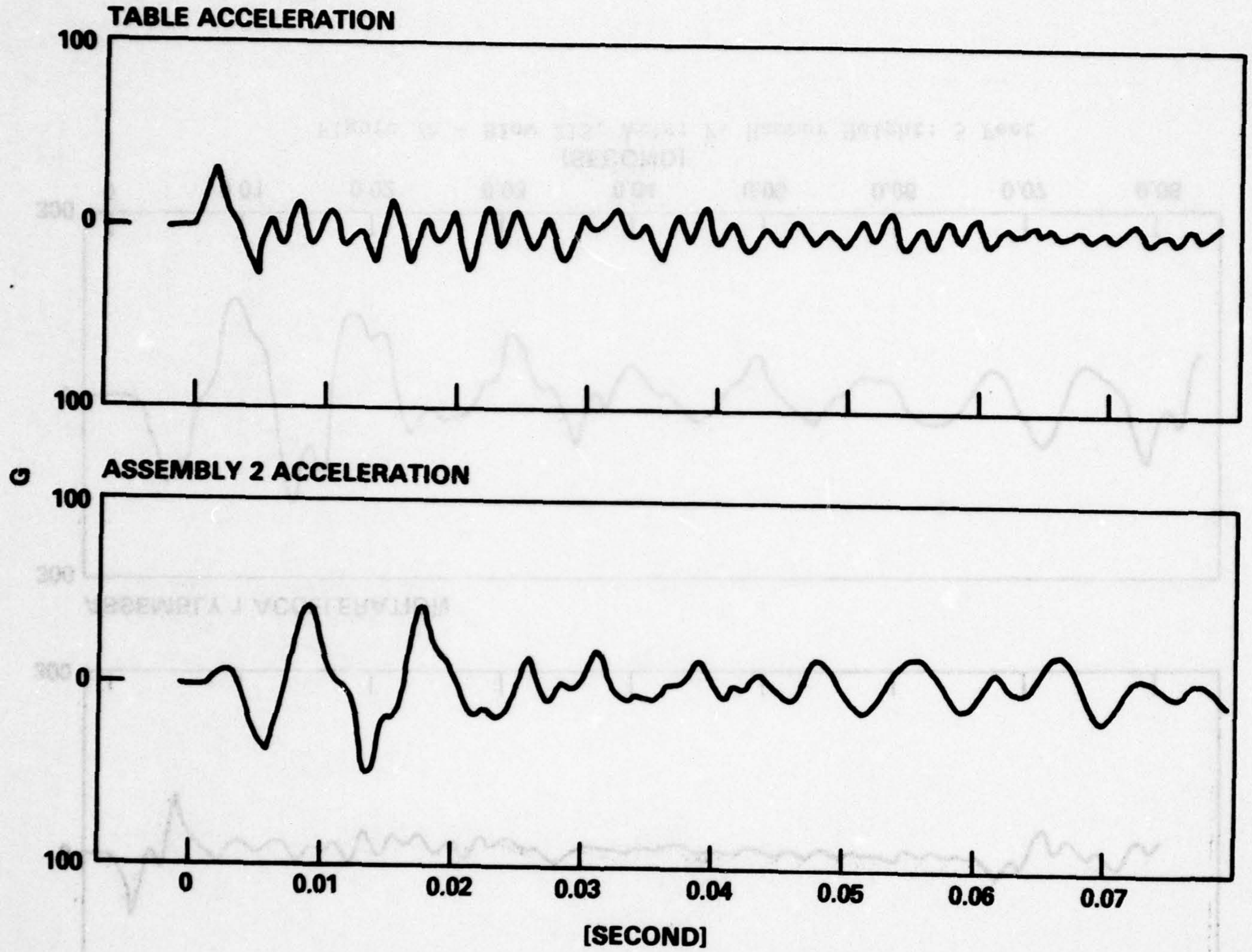


Figure 7i - Blow 216, Axis: Y, Hammer Height: 1 Foot

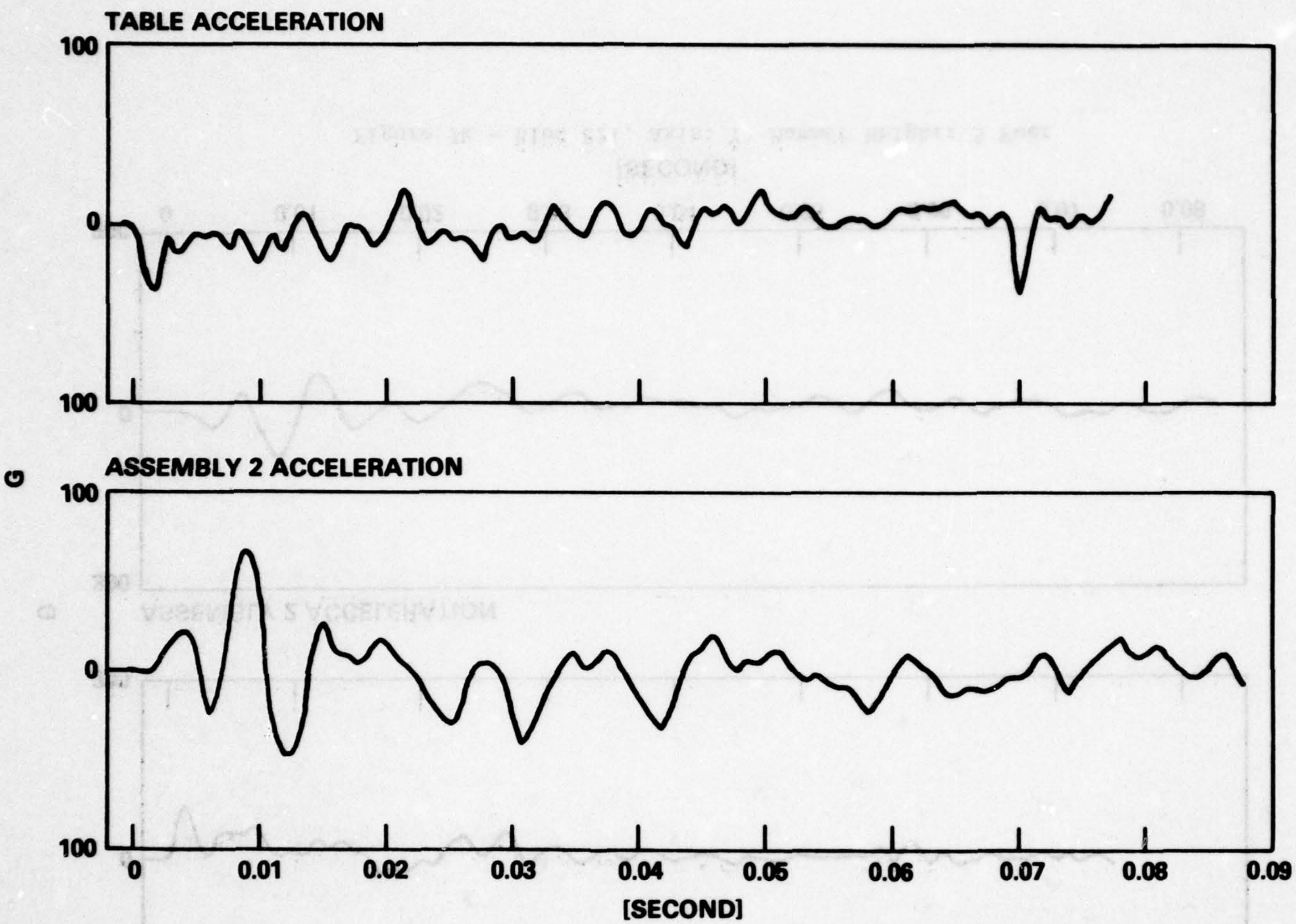


Figure 7j - Blow 220, Axis: Y, Hammer Height: 3 Feet

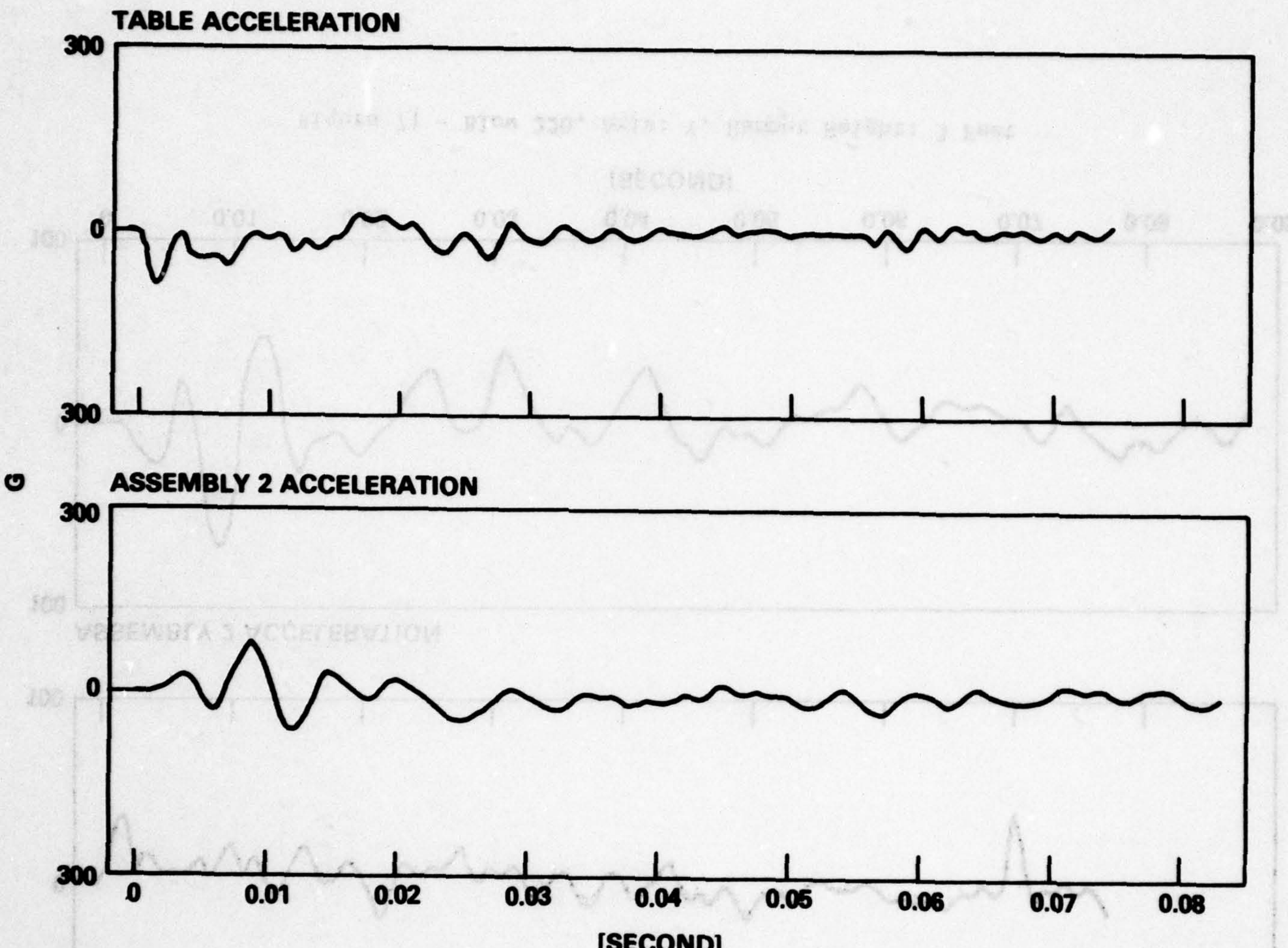


Figure 7k - Blow 221, Axis: Y, Hammer Height: 5 Feet

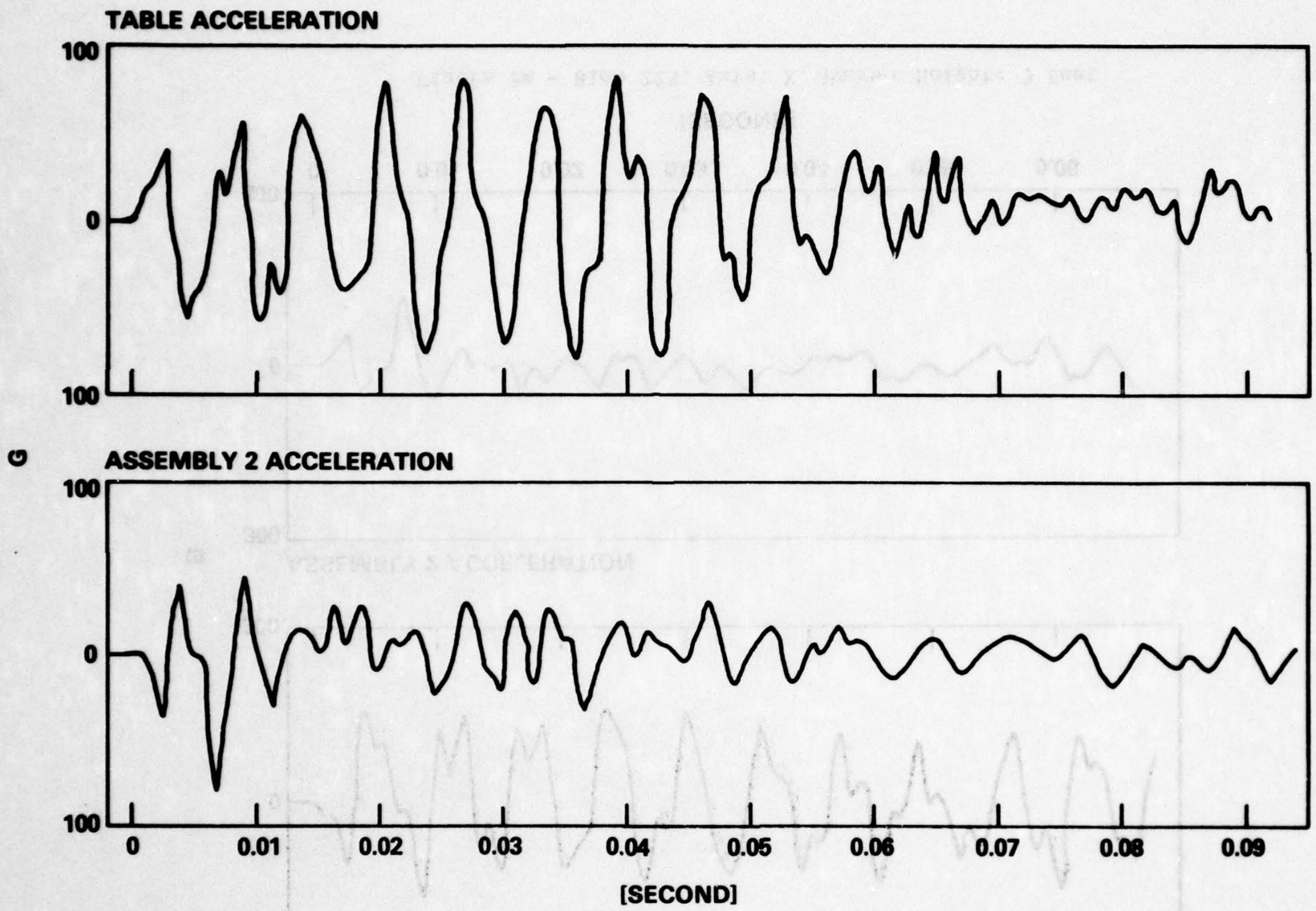


Figure 71 - Blow 222, Axis: X, Hammer Height: 1 Foot

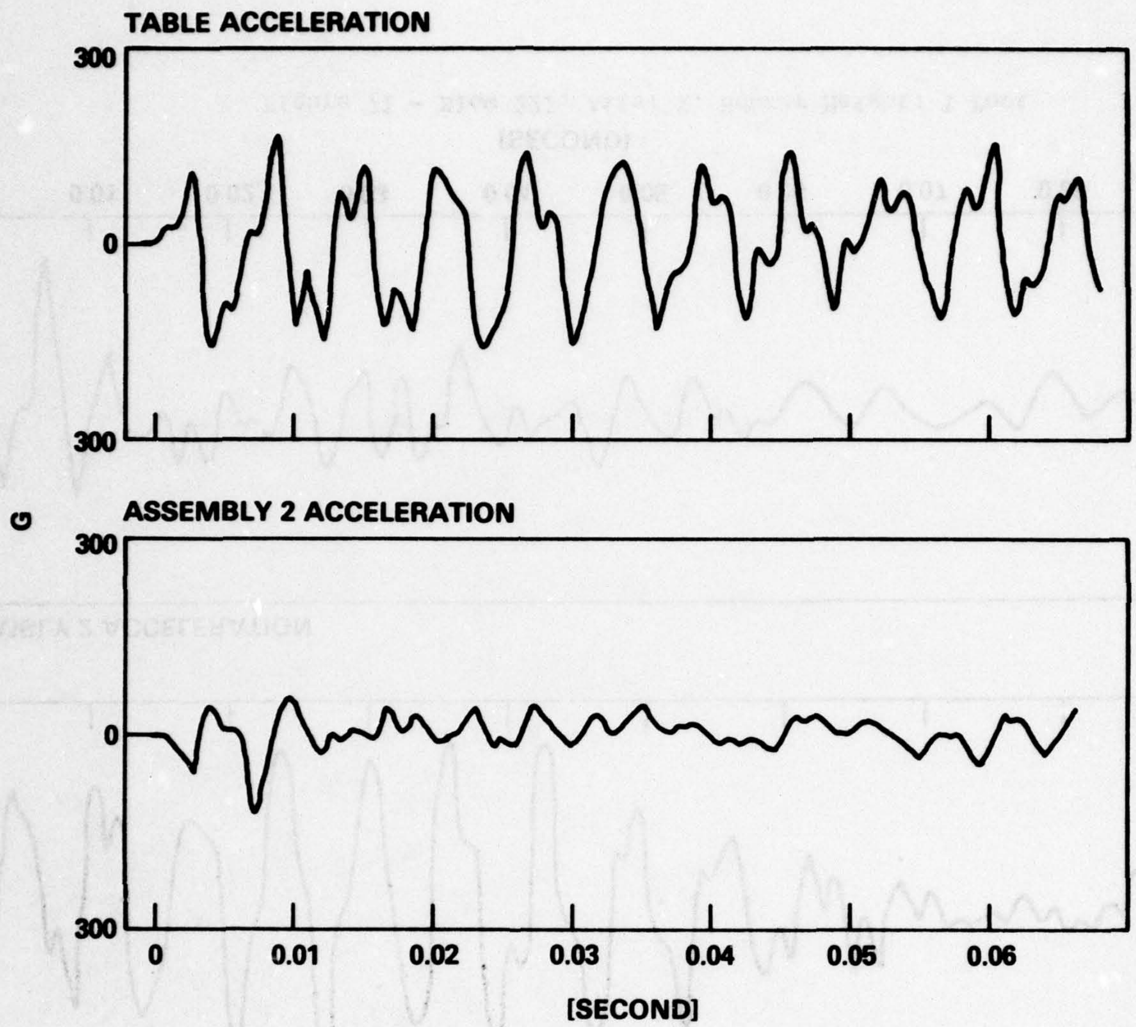


Figure 7m - Blow 223, Axis: X, Hammer Height: 3 Feet

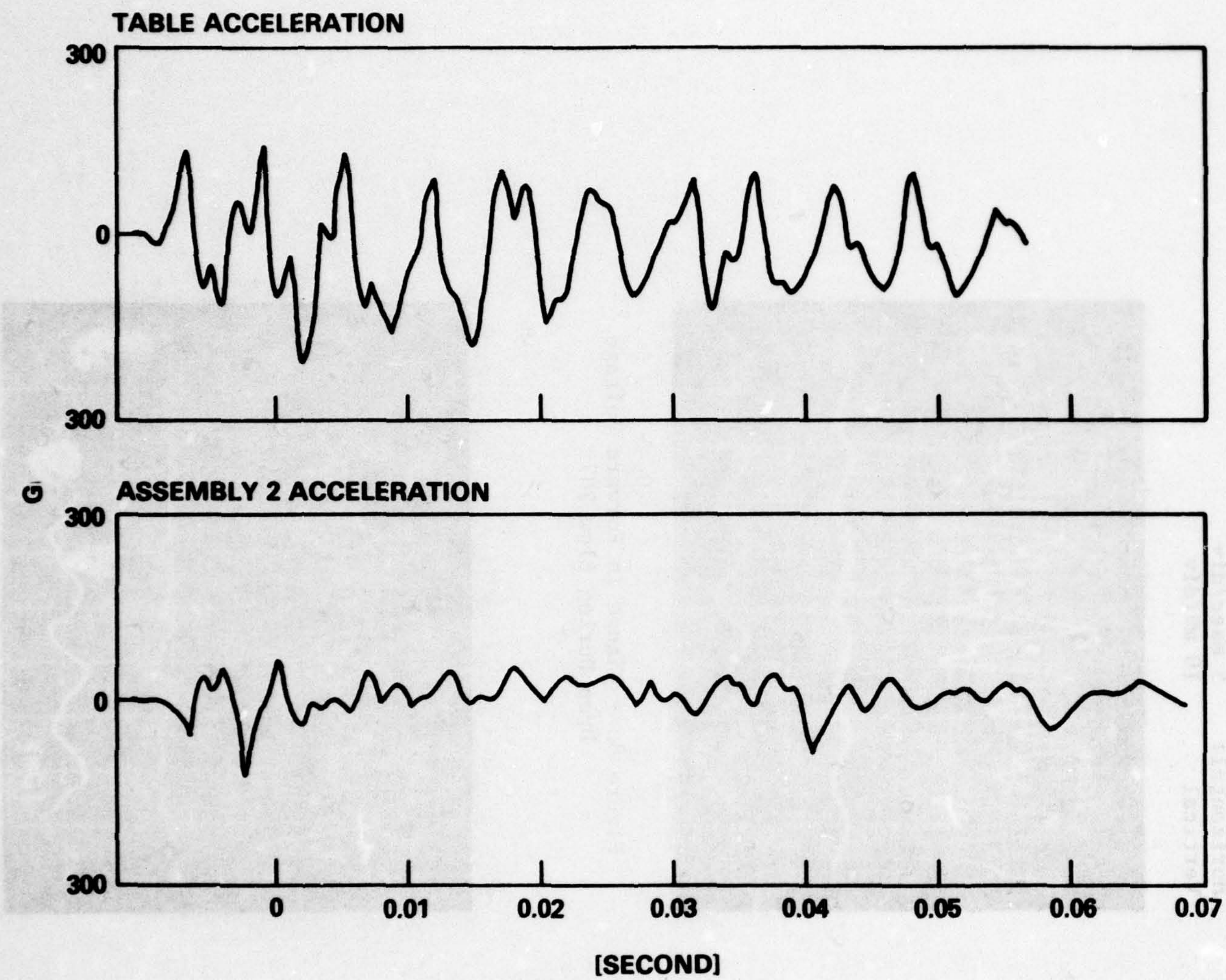


Figure 7n - Blow 224, Axis: X, Hammer Height: 5 Feet

Assembly 1 - (Figures 8a and 8b)

Top Waveform:	Acceleration
Horizontal	5 msec/div
Vertical	Uncalibrated
Middle Waveform:	Voltage Drop of Device 2
Horizontal	5 msec/div
Vertical	10 mV/div
Bottom Waveform:	Voltage Drop of Devices 1 and 2
Horizontal:	5 msec/div
Vertical	10 mV/div

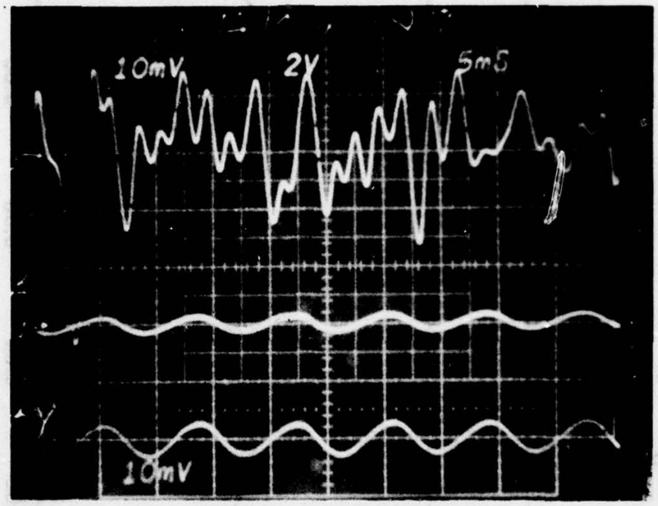


Figure 8a - Change in Forward Voltage Drop During Blow 207

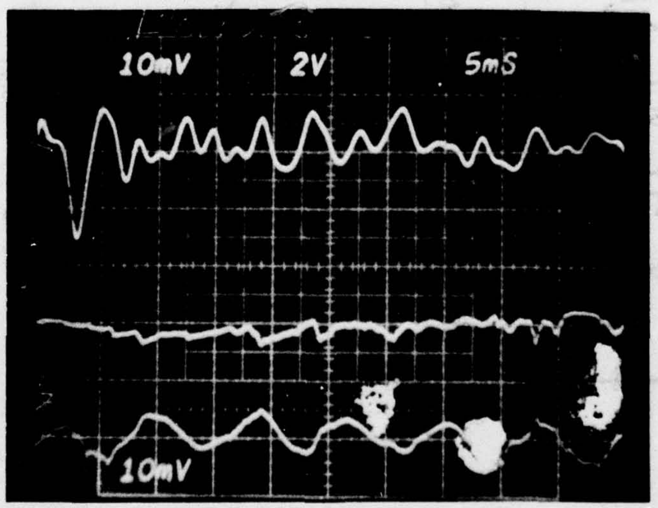


Figure 8b - Change in Forward Voltage Drop During Blow 208

Assembly 1 - (Figures 8c and 8d)

Top Waveform:	Acceleration
Horizontal	5 msec/div
Vertical	Uncalibrated
Middle Waveform:	Voltage Drop of Device 2
Horizontal	5 msec/div
Vertical	10 mV/div
Bottom Waveform:	Voltage Drop of Devices 1 and 2
Horizontal	5 msec/div
Vertical	10 mV/div

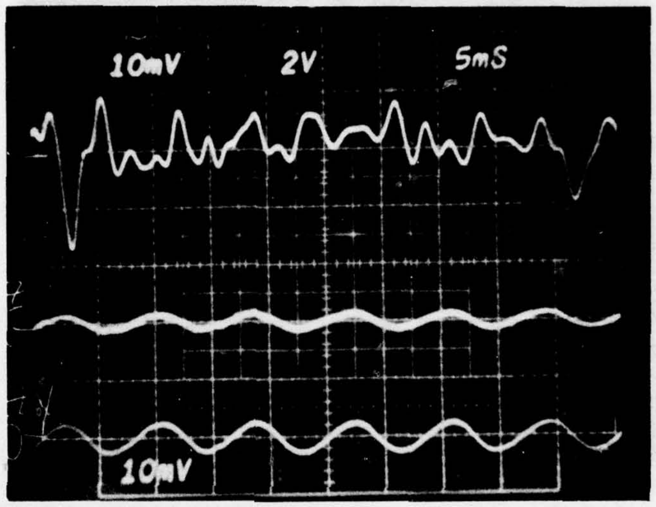


Figure 8c - Change in Forward Voltage Drop During Blow 209

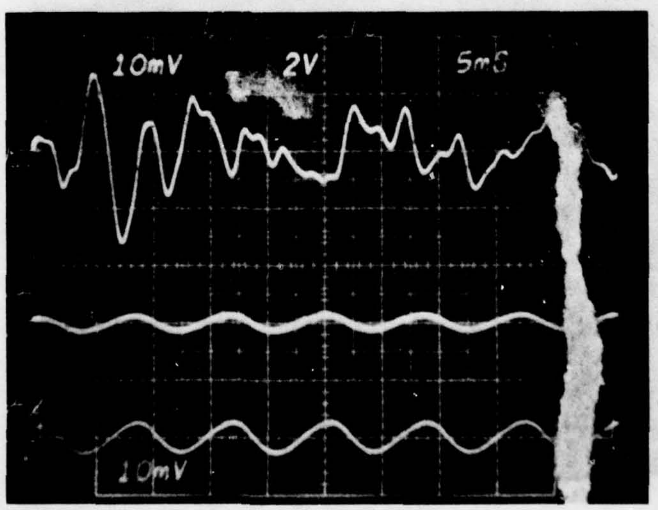


Figure 8d - Change in Forward Voltage Drop During Blow 210

Assembly 1 - (Figures 8e and 8f)

Top Waveform	Acceleration
Horizontal	5 msec/div
Vertical	Uncalibrated
Middle Waveform:	Voltage Drop of Device 2
Horizontal	5 msec/div
Vertical	10 mV/div
Bottom Waveform:	Voltage Drop of Devices 1 and 2
Horizontal	5 msec/div
Vertical	10 mV/div

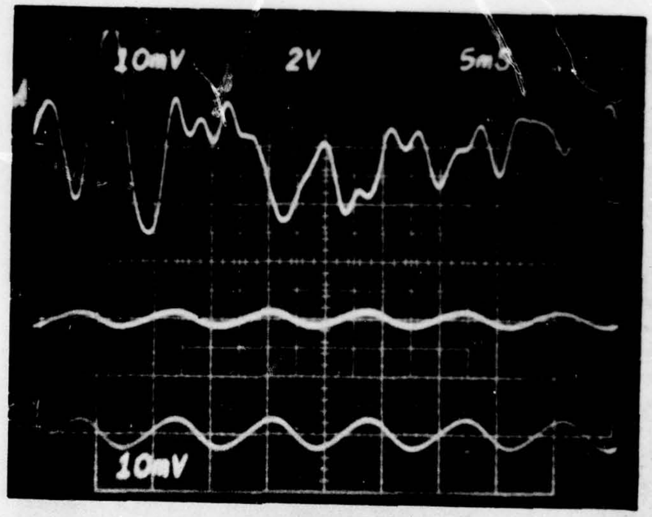


Figure 8e - Change in Forward Voltage Drop During Blow 211

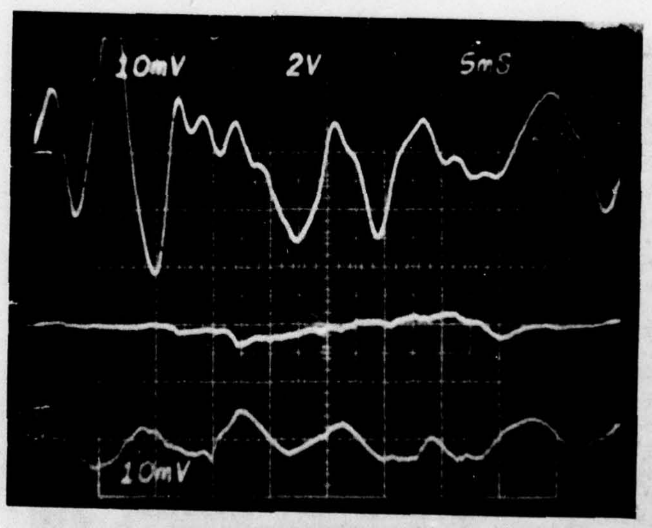


Figure 8f - Change in Forward Voltage Drop During Blow 212

Assembly 1 - (Figures 8g and 8h)

Top Waveform:	Acceleration
Horizontal	5 msec/div
Vertical	Uncalibrated
Middle Waveform:	Voltage Drop of Device 2
Horizontal	5 msec/div
Vertical	10 mV/div
Bottom Waveform:	Voltage Drop of Devices 1 and 2
Horizontal	5 msec/div
Vertical	10 mV/div

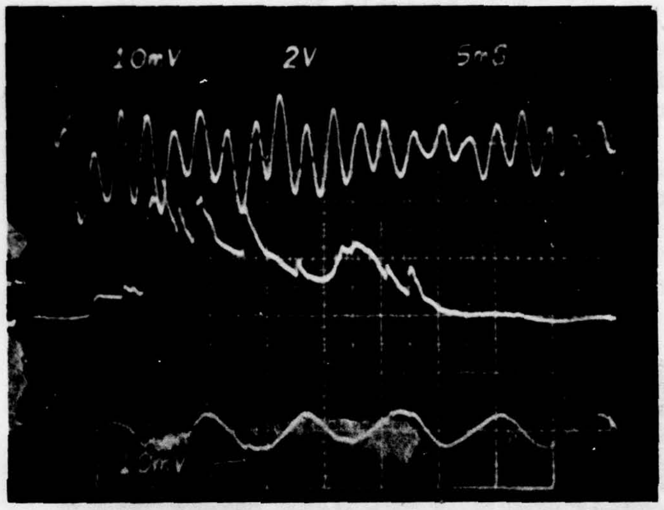


Figure 8g - Change in Forward Voltage Drop During Blow 213

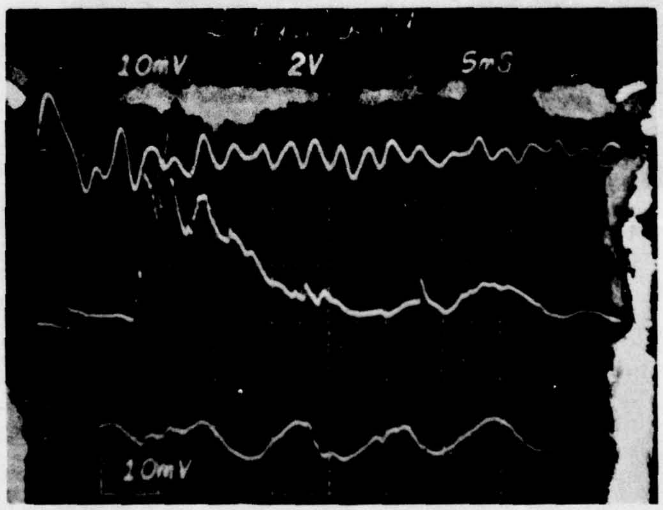


Figure 8h - Change in Forward Voltage Drop During Blow 214

Assembly 1

Top Waveform:	Acceleration
Horizontal	5 msec/div
Vertical	Uncalibrated
Middle Waveform:	Voltage Drop of Device 2
Horizontal	5 msec/div
Vertical	10 mV/div
Bottom Waveform:	Voltage Drop of Devices 1 and 2
Horizontal	5 msec/div
Vertical	10 mV/div

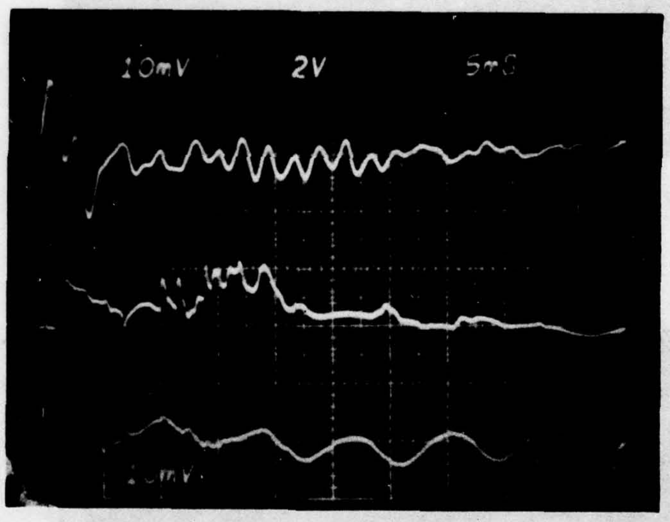


Figure 8i - Change in Forward Voltage Drop During Blow 215

Assembly 2 - (Figures 8j and 8k)

Top Waveform:	Acceleration
Horizontal	5 msec/div
Vertical	Uncalibrated
Middle Waveform:	Voltage Drop of Device 2
Horizontal	5 msec/div
Vertical	10 mV/div
Bottom Waveform:	Voltage Drop of Devices 1 and 2
Horizontal	5 msec/div
Vertical	10 mV/div

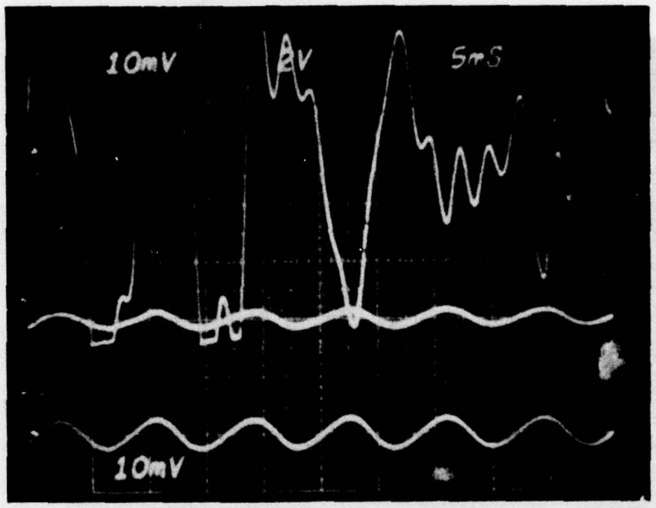


Figure 8j - Change in Forward Voltage Drop During Blow 217

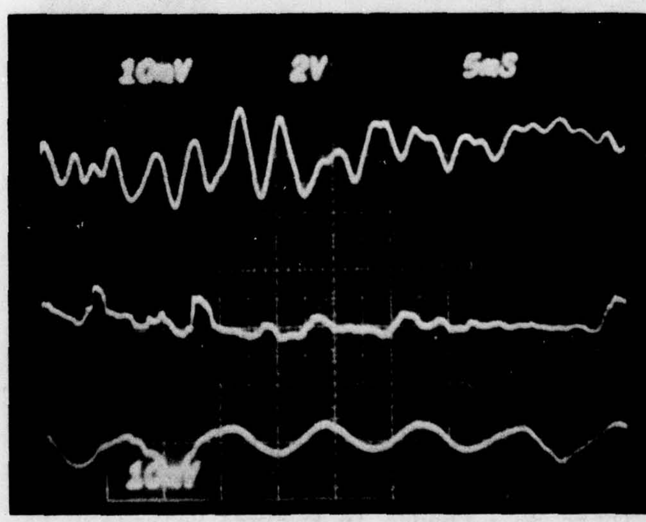


Figure 8k - Change in Forward Voltage Drop During Blow 219

Assembly 2 (Figures 81 and 8m)

Top Waveform:	Acceleration
Horizontal	5 msec/div
Vertical	Uncalibrated
Middle Waveform:	Voltage Drop of Device 2
Horizontal	5 msec/div
Vertical	10 mV/div
Bottom Waveform:	Voltage Drop of Devices 1 and 2
Horizontal	5 msec/div
Vertical	10 mV/div

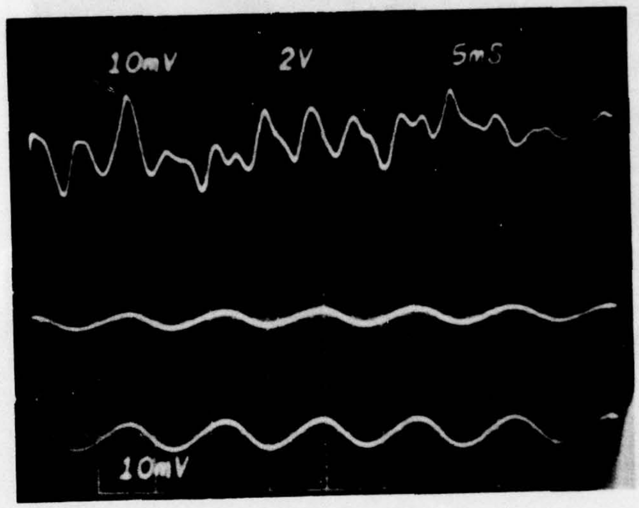


Figure 81 - Change in Forward Voltage
Drop During Blow 220

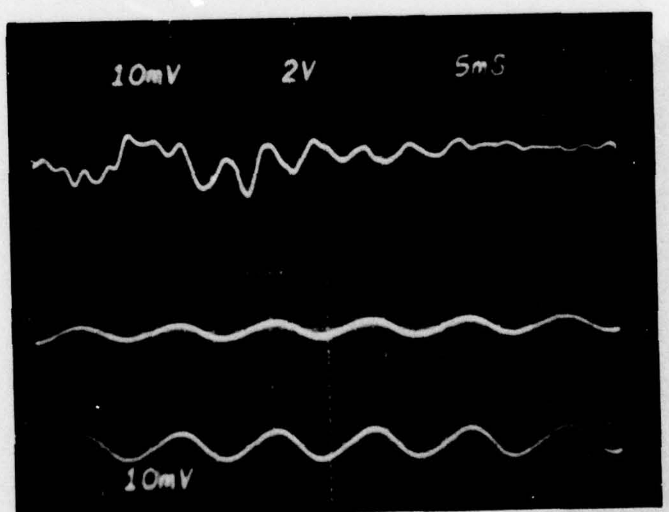


Figure 8m - Change in Forward Voltage
Drop During Blow 221

Assembly 2 (Figures 8n and 8o)

Top Waveform:	Acceleration
Horizontal	5 msec/div
Vertical	Uncalibrated
Middle Waveform:	Voltage Drop of Device 2
Horizontal	5 msec/div
Vertical	10 mV/div
Bottom Waveform:	Voltage Drop of Devices 1 and 2
Horizontal	5 msec/div
Vertical	10 mV/div

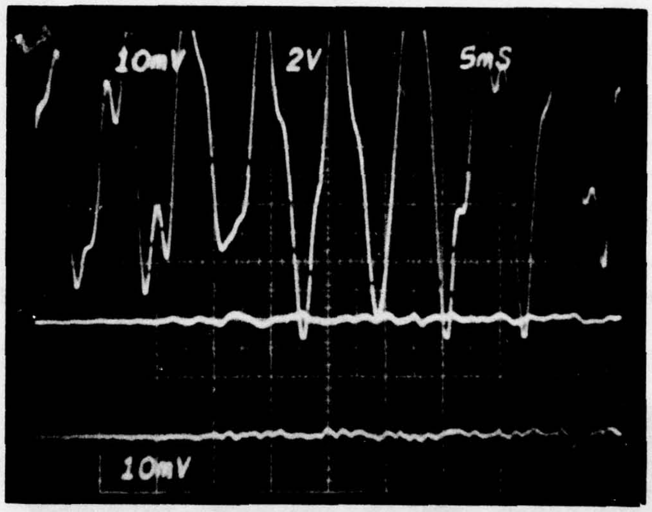


Figure 8n - Change in Forward Voltage Drop During Blow 222

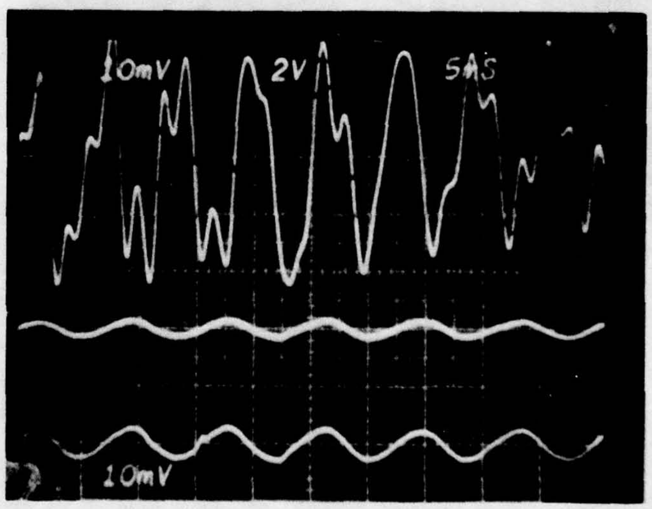


Figure 8o - Change in Forward Voltage Drop During Blow 223

Assembly 2

Top Waveform:	Acceleration
Horizontal	5 msec/div
Vertical	Uncalibrated
Middle Waveform:	Voltage Drop of Device 2
Horizontal	5 msec/div
Vertical	10 mV/div
Bottom Waveform:	Voltage Drop of Devices 1 and 2
Horizontal	5 msec/div
Vertical	10 mV/div

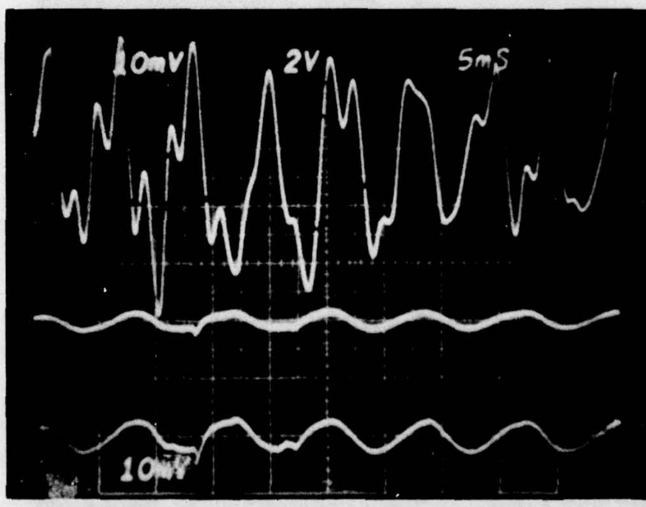


Figure 8p - Change in Forward Voltage Drop During Blow 224

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